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2. Patent application number *(The Patent Office will fill in this part)* — **0019958.8** — 14 AUG 2000

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — DR PHILIP JOHN MARTIN
6, THE MANWARINGS
HORSMONDEN,
KENT. TN12 8NQ

   Patents ADP number *(if you know it)* — 7960263001

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — LOCATING SYSTEM

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

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Locating System

This invention generally relates to locating systems suitable for locating lost objects. It is particularly suitable for locating lost pets but can also be used for locating lost people and objects such as lost files.

Electronic tagging devices are known for preventing theft of items from shops. However, although these tags are small and cheap, they can only be detected at relatively short ranges, typically a couple of metres. Security tags which transmit coded information in response to an interrogation signal are also known for identifying pets and also items such as antiques. However, again these tags can only be detected at very short ranges, typically a few centimetres. It is possible to conceive of tags with increased ranges, for example using a simple, battery-powered radio frequency transmitter, but to achieve ranges of more than a few metres requires a significant transmitter output power. However, the transmitter and the batteries required to power it even for a few hours would be too large to be easily carried by a small domestic pet. Furthermore, even with careful, low-power design it would be difficult to achieve a battery life of more than a day or two from batteries ordinarily used for portable electronic devices. By way of comparison, even highly sophisticated mobile phones which have been optimised for low power operation rarely achieve a battery life of more than four hours talk time.

There thus exists a need for an improved tag suitable for, among other things, locating domestic pets. Such a tag should be small enough to be easily carried by the pet, which could be a small cat, and yet provide a range of at least 10m and a battery life of, preferably, more than 1 month. A 10m range is sufficient to provide considerable assistance in searching for a lost cat, although a greater range is desirable for larger pets such as dogs. A further requirement is that the tag at least should be affordable. The

detection equipment, which is likely to be needed only infrequently, could if necessary be hired rather than purchased so that the receiver cost, whilst important, is a less significant factor.

A pet owner will want to be able to identify and locate his or her particular pet. Furthermore, since a geographical locality may contain more than one tagged pet the system should preferably be able to distinguish between signals from two or more different tags in order to be able to determine and identifying code for each tag. It is not necessary, however, to uniquely identify each animal providing an owner can be reasonably confident that it is their pet they are locating.

A different but related set of problems is encountered when wishing to locate lost files. Since files are generally stored together, a system for locating a lost file must be able to distinguish the signal of one file from those of its neighbours. Generally speaking there likely to be many more different files in any single place than pets. Thus a greater distinguishing capability is required. However, it will normally be possible to operate a file locating system with the detector less than 1m from the tagged files, so that range is less important. A small physical size and a long battery life are probably more important requirements and, where many thousands of files are to be tagged, it is important that the tag cost is minimised.

A system for tracking objects in a semiconductor fabrication facility using spread spectrum tags with a unique ID is known from US 5,119,104. A system for confining animals using spread spectrum transmissions is described in US 5,769, 032. A spread spectrum signal is transmitted to a receiver on the animal's collar and the signal strength is used to determine whether the animal is near a boundary.

A CDMA spread spectrum asset tracking system is described on the web site of the Radiocommunications Agency. This briefly alludes to a transponder comprising a 0.1W spread spectrum transmitter, a microcontroller and a paging-type receiver for commands. The transponder is located by time-of-arrival measurements using multiple

base stations and a control/processing site using hyperbolic navigation techniques. The power requirements of such a tag would make it unsuitable for use for tracking pets. Furthermore, the relatively high power transmitter (that is, for a spread spectrum system) and paging-type receiver suggests that the system is intended for use at relatively large ranges.

A system for tagging domestic pets must be able to cope with a relatively large concentration of tags in a relatively small geographical area. The described asset tracking system uses maximal length (m-sequence) coding which is unsuitable for pet tagging and related applications because it has insufficient power to distinguish between transmissions from different tags (the system may instead rely on selectively requesting transmissions via the paging receiver). If used for pet tagging the system would also be subject to the "near-far" problem (where the correlation with a strong signal having an incorrect code is greater than with a weaker, more distant signal with the correct code).

According to a first aspect of the invention there is therefore provided a tag for locating an object, the tag comprising: an rf transmitter to transmit a coded signal; and an acoustic command receiver to receive an acoustic command; and wherein the coded signal is transmitted in response to reception of an acoustic command.

The rf transmitter could be a narrow band transmitter such as an FSK (Frequency Shift Keying) data transmitter but is preferably a spread spectrum transmitter. Using an acoustic command receiver simplifies the command receiver circuitry and enables the provision of a smaller, lower power consumption tag.

Use of acoustic rather than, for example, rf commands allows the tag to take advantage of the differing characteristics of acoustic as opposed to rf propagation. For example, acoustic commands can be received within a metal enclosure which would substantially attenuate an rf command. The processing gain provided by spread spectrum transmission means that the tag transmitter output is not so greatly affected by such problems. A further advantage of using an acoustic command transmitter is,

paradoxically, its relatively limited range. The effect of this is that only a few tags near the command transmitter need be stimulated, reducing the potential problem associated with transmitted signals from different tags causing interference at the tag detector/receiver.

Preferably the rf transmitter is a direct sequence spread spectrum (DSSS) transmitter as such transmitters are simpler and cheaper to construct than frequency hopping devices.

In one embodiment the spreading sequence comprises a Gold code. These codes are described in more detail later. Such codes are relatively simple to implement whilst providing sufficient codes to reduce the risk of collision between transmissions from different tags, providing the number of tags excited by the command transmitter is not too great. Use of a Gold code allows improved code domain multiple access (CDMA) for distinguishing between tags.

There is a balance to be achieved between the number of different codes provided, the processing gain provided by a code and the command transmitter range. Advantageously the spreading sequence for the DSSS transmitter is less than or equal to 1023 chips (that is spreading code bits) and more preferably less than 255 chips. For an acoustic command receiver these values allow a reasonable compromise between acquisition time for the coded transmissions, number of codes and collision avoidance between transmitting tags.

Preferably the transmitter provides an ERP of 10mW, more preferably ≤5mW, and most preferably ≤2mW. An ERP of 1mW provides sufficient transmit range for a tag with an acoustic command receiver, where the effective range is dominated by the command transmission range.

In an alternative embodiment the spreading sequence comprises a Kasami code, which at the expense of slightly increased tag complexity and greater receiver complexity,

provides many more CDMA codes. Thus a Kasami code is useful for tags detectable at greater ranges, and also when the acoustic command receiver is substituted by a longer range command receiver, such as an rf command receiver. The larger number of codes for the same sequence length provided by a Kasami code makes this code particularly advantageous when there is no modulation by baseband data, as described below.

In on embodiment the spread spectrum code is modulated by baseband data which includes a tag identity. Thus once the tag detector has locked onto the code the tag identifier can be read. The combination of the code and the tag identifier together serve to distinguish between a large number of different tags.

In a preferred embodiment the command receiver is responsive to acoustic commands which are substantially inaudible to most adult humans. Thus in one embodiment a tag is caused to transmit by means of a dog whistle. Such high frequency acoustic signals carry well and cause little disturbance to others, which is important when searching a neighbourhood for a lost pet. The command receive can be chosen to be responsive to a tone of a particular frequency or to a range of frequencies above a predetermined 3dB cut-off frequency. Greater sensitivity and increased immunity to false triggers is achieved by using a narrow bandwidth tone detector, with a bandwidth of ≤1KHz, more preferably ≤500Hz and most preferably ≤100Hz. The narrower the frequency band, however, the more precisely tuned must be the whistle or other command transmitter.

According to a second aspect of the invention there is provided a tag for locating an object, the tag comprising: a command receiver to receive a command; and a spread spectrum rf transmitter, the spread spectrum transmitter having a spreading code; wherein the transmitter transmits a spread spectrum signal responsive to a received command; and wherein the transmitted signal conveys the spreading code unmodulated by baseband data.

By transmitting only the spreading code, both the tag and tag detector are simplified. Effectively the spreading code sequence itself is used for identifying the tag rather than

any baseband data modulated onto the spread spectrum transmitted signal. The tag can be considered to be transmitting a single bit of baseband information, namely the presence or absence of the spreading code. With such a system it is possible to encode further information by, for example, altering a length of time of the code transmission, but it is preferable that the spreading code alone conveys the identity information of the tag, that is, only spreading code information is transmitted.

Either a Gold or a Kasami code can be used with such a tag, although Kasami codes are preferred as they provide a larger number of codes for a given sequence length and hence a greater number of different tag identifiers. Because the code is not modulated by baseband data, the chip rate of the spread spectrum transmitter can be increased without greatly adding to the cost or complexity of the tag. This allows longer spreading sequences to be used for the same detector/receiver acquisition time, which again increases the number of available codes.

Preferably the spreading sequence is less than ~16K chips in length, more preferably, less than ~4K chips in length. The improved CDMA access capabilities provided by the larger number of codes allows a system with increased range to be constructed for a given risk of collision between signals from tags with the same spreading code. Likewise the longer code provides greater processing gain and hence increased range. Thus such a system is suitable, for example, for locating animals which stray further afield such as larger dogs.

To achieve increased command transmitter range with such a system an rf command receiver is preferred. This can be a straightforward AM or FM receiver with tone detection circuitry or a more complex receiver for responding to a predetermined pulse sequence, or a simple tuned circuit for responding merely to the presence or absence or an rf carrier at the appropriate frequency. With this latter arrangement it is preferred that the receiver is sensitive to a carrier within a relatively narrow band, ≤1% and preferably ≤0.1% of the carrier frequency, to provide the necessary sensitivity and selectivity.

Either of the above described tags can be powered either by batteries or by solar power, or by a combination of the two. When powered by solar power it is clearly desirable to incorporate some form of energy storage within the tag, such as a rechargeable battery or a large capacitor.

The command receiver is preferably arranged to switch power to the transmitter so that in a quiescent state it is only the receiver which is drawing power. Since the power consumption of the command receiver can be reduced below 1mA, even a button cell can provide many months of life. Preferably when a command is received the tag transmits for a predetermined interval before power to the transmitter is once again cut off.

The turn-on signal received by the command receiver can also be used for transmitting a special sequence before the spread spectrum code to enable the detector/receiver to lock onto the code more quickly; preferably the transmit oscillator is allowed to settle before such a sync sequence is transmitted.

A set of tags is also provided in which each tag has a different spreading sequence. Most generally, the spreading sequences can be of different lengths, but for simplicity of tag detector design it is preferred that a set of codes of a chosen length is employed. As described below, Gold and Kasami codes are generated by means of shift registers with EXOR feedback taps. For a given Gold or Kasami sequence a so called "preferred pair" of shift register tap sets is required and this preferred pair will generate one set of Gold or Kasami codes.

For a given length of shift register there is more than one preferred pair of tap sets, generally with different cross-correlation properties. Thus for a given spreading sequence code length, it may be desirable to use codes based upon all the preferred pairs available for that sequence length, so as to get maximum benefit from the number of different codes available. In practice, so called "balanced" codes (in which the number

of 1's and 0's differs by one) are preferred as these do not generate a dc component in the output signal.

If space allows it is desirable to include a battery monitor within the tag since, generally speaking, the tag will only be commanded to transmit infrequently, making it difficult to keep a track of when batteries ought to be replaced. Alternatively, however, tag batteries can be replaced every few months as a matter of routine. The battery monitor preferably tests a battery under load since this gives a better indication of the battery's condition. Preferably the battery monitor should not itself draw excess power and may therefore comprise an indicator, such as an LED (Light Emitting Diode), with a short "on" duty cycle.

According to another aspect of the invention there is provided a detector for locating an object having a tag, the detector comprising: a direct sequence spread spectrum (DSSS) receiver for receiving from the tag a spread spectrum signal based on a Gold or Kasami code; a first aerial coupled to the receiver; input means for user selection of a said Gold or Kasami code; and indicating means for indicating when a tag with the selected code is detected.

The input means allows the user to select the spreading code of the tag to be located and the DSSS receiver will, generally speaking, then only lock onto signals from tags with this code. If a tag includes means for modulating baseband identity data onto the spread spectrum signal, this can also be entered into the detector. In such a system there are two parameters which should be matched to identify a tag - the spreading code and the identity data modulated onto it.

In a system where there is a limited number of codes, which is most likely where the is a short range acoustic command receiver, there is the possibility of locating a tag with the correct spreading code but the wrong identity. In this situation it is helpful to a user if separate indications of code lock and tag identity match are provided and/or some

indication is provided of the receiver locking onto a tag with the correct spreading sequence but an incorrect identity code.

Where the detector is used with a tag having an acoustic command receiver, the acoustic command can be simply and cheaply provided by means of, for example, a dog whistle. In this case, for user confidence it is helpful if the detector indicates when an acoustic command is transmitted. In other embodiments the receiver includes means to issue an acoustic command signal to a tag, for example, by means of a piezoelectric transducer. Alternatively the detector may include an rf command transmitter.

During the interval in which the tag is expected to be transmitting the receiver advantageously provides an indicator, such as a flashing LED, showing that the receiver is searching for a transmitted signal which may be present. If desired the receiver can be arranged only to search for a code lock during this period.

The detector is preferably portable and hand-held and includes a directional aerial. This may be mounted directly on the detector or separately attachable to the detector. In a preferred embodiment the detector includes an approximately omnidirectional antenna and a directional antenna such as a Yagi, so that the omnidirectional antenna can be used to determine whether the tag is nearby and the directional antenna can be used to locate the approximate direction in which the tag is to be found.

In a further aspect the invention provides a tag for use with a tag detector radar, the tag comprising: a pseudonoise (PN) code generator for generating a spreading code for a spread spectrum system; and a modulator and antenna combination for providing a modulated radar return from the tag; wherein the PN code generator is coupled to the modulator for modulating the radar return with the spreading code.

The pseudonoise (PN) code is used to modulate a radar return rather than to directly modulate a transmitted signal as in conventional spread spectrum transmitters. The same codes can, however, be used, and include m-sequence codes, Gold codes and Kasami codes. The usual spread spectrum code properties are desirably, namely a high autocorrelation coefficient and a low cross-correlation coefficient for the pseudorandom sequence.

The spread spectrum PN code can be modulated onto the radar return using either phase or amplitude modulation. For phase modulation the incident radar signal is mixed with the PN code using, for example, a Schottky diode, or other low-bias diode, or a dual gate FET. Amplitude modulation can be achieved using a switch, controlled by a PN code generator to either load the aerial or short out a dipole.

As in the tags described above, power to the PN code generator can be switched. In an alternative embodiment, however, the tag can be powered using the incident rf radar radiation. This is particularly advantageous in short-range systems.

Dispensing with the tag transmitter allows the tag to be smaller and cheaper and to have a reduced power consumption. This is particularly advantageous where the spreading sequence is long, thus requiring a relatively high chip frequency to allow a reasonable code acquisition time (in the applications envisaged, of the order of 1 second). Thus this arrangement is particularly useful when the spreading sequence is equal to or greater in length than 1023 chips and/or where the chip clock frequency is equal to or greater than 5MHz, 10MHz, or particularly 20MHz.

According to a further aspect of the invention there is provided a radar detector for a tag providing a radar return modulated with a spread spectrum code, the detector comprising a radar front end coupled to a spread spectrum receiver.

Preferably the system includes a high pass filter to reduce the level of a dc component in the baseband signal due to unmodulated returns from the tag. In an AM system, the spread spectrum receiver can be simpler than conventional phase shift keying spread spectrum receivers as there is no need for carrier tracking (or, equivalently at dc, I and Q processing paths) so that correlation is achieved using a single code slip and track/lock loop.

The radar can use either a single aerial for transmission and reception or, for improved isolation, separate transmit and receive antennas. Preferably high gain, directional antennas are used to provide greater incident power, greater return signal sensitivity, and improved directionality for more accurate tag location and to reduce the volume interrogated, reducing the level of mutual interference between returns from different tags.

These and other aspects of the invention will now be further described, by way of example only, with reference to the accompanying figures in which:

Figure 1 shows use of a spread spectrum tag and detector, according to an embodiment of the invention, to locate a cat;

Figure 2 shows the architecture of a spread spectrum tag;

Figure 3 shows a command receiver for the tag of Figure 2;

Figure 4 shows a spread spectrum transmitter for the tag of Figure 2;

Figures 5a-c show, respectively, a PN code generator, a time delay element, and an m-sequence shift register;

Figure 6 shows a second PN code generator;

Figure 7 shows hardware for generating a modulated spread spectrum transmission;

Figure 8 shows hardware for generating a start-up synchronisation sequence;

Figure 9 shows a battery monitor;

Figures 10a-c show, respectively, a physical layout, side, and top views of a tag;

Figures 11a and b show, respectively, a physical layout and a side view of a second embodiment of a tag;

Figures 12a and b show, respectively, first and second embodiments of a detector for the tag of Figure 2;

Figure 13 shows a block diagram of a tag detector according to an embodiment of the invention;

Figure 14 shows an rf front end for the detector of Figure 13;

Figures 15a and b show, respectively, first and second embodiments of a DSSS receiver for the detector of Figure 13;

Figure 16 shows use of a spread spectrum tag with a radar detector to locate a file;

Figures 17a-e show, respectively, a spread spectrum tag, a data modulator circuit element, first and second rf mixers and a tag power supply;

Figure 18 shows a physical embodiment of the tag of Figure 17; and

Figures 19a and b show, respectively, a radar front end and a spread spectrum receiver for the tag of Figure 17.

Referring to Figure 1, this shows a tag 10 fitted to a collar 12 of a lost cat 14. Its owner 16 is equipped with a tag detector 18 and a dog whistle 20. The owner 16 blows on the dog whistle 20 to start tag 10 transmitting for a predetermined interval, which may be in the range 10-30 seconds, but which can be longer, for example up to 2, 5, or 10 minutes. Whilst the tag is transmitting the owner uses an omnidirectional aerial (not shown in Figure 1) on detector 18 to ascertain that the tagged cat 14 is in the vicinity, and then switches to directional aerial 22 to identify the direction from which the transmission originates. In this way the lost cat 14 can be tracked down and retrieved.

Referring now to Figure 2, this shows the internal architecture of the spread spectrum tag 10 of Figure 1. A command receiver 20 is responsive to the dog whistle to control switch 22 to apply power from battery 24 to spread spectrum transmitter 26, which then radiates on antenna 28. The transmit power depends upon the desired range and battery life but, as will be shown below, a power of 1mW is sufficient for locating a lost cat.

Command receiver 20 draws power continuously from cell or cells 24 and thus must be configured for low current consumption. The principles of such design are well known to those skilled in the art. Use of even an AAA cell is undesirable for a cat tag because of its size and weight and button or similar type cells, for example silver oxide cells, offer a smaller and lighter option.

To lengthen the battery life of such a cell it is preferable that command receiver 20 is relatively simple and one way of achieving this is to use acoustic rather than rf commands. The command receiver and switch are preferably configured so that power is applied to the spread spectrum transmitter for a predetermined time interval, as indicated above, which helps to reduce the effects of false or unwanted triggers. As described above, an owner blowing the dog whistle would stimulate all tags within range to transmit and it is therefore beneficial if when triggered a tag transmits for a relatively limited period of time. In an alternative arrangement some selectivity may be provided by arranging for subsets of tags to respond to different command signals to

reduce the likelihood that any one tag will be unnecessarily triggered. This can be achieved by using acoustic stimuli of different frequencies and/or pulse patterns.

Continuing to refer to Figure 2, the tag preferably (where space allows) incorporates a battery monitor 30 which checks the condition of battery 24 at intervals and indicates by means of flashing LED 32 when power is low.

Optionally one or more solar cells 34 may be fitted to the tag to trickle charge a (rechargeable) battery 24 via charge 36. Alternatively, battery 24 may be eliminated and replaced by a large value (for example, 1 Farad) capacitor such as is used for memory "battery" back-up. The tag should have sufficient surface area exposed to light to generate enough power for the tag if the tag is to be entirely reliant on solar power, or where this condition is not met, solar power may be used to extend battery life.

Figure 3a shows an acoustic command receiver 20 and Figure 3b shows an alternative rf front end 300. In Figure 3a microphone 302 is coupled to an input of preamplifier 304 and thence to bandpass filter 306 to broadly select the frequencies of interest. The output of filter 306 provides an input for detector 308 which is preferably a tone detector (for example, monostable-based) but which could also be a pulse detector. The output of detector 308 is coupled to decision device 310 (for example, a comparator) which provides outputs 312 and 314 to control switch 22 and to provide a power-on-reset signal respectively.

Alternative rf front end 300 demodulates a tone transmitted on an rf carrier, which is then processed in the same way as the audio input to filter 306. Since in general the frequency of the tone modulating the rf carrier will be known much more precisely than the frequency of the acoustic signal from the dog whistle detector 308 can be arranged to be sensitive to a very narrow band of tone frequencies, allowing much greater selectivity between received commands. Moreover, receiver 316 coupled to antenna 318 can be arranged to have a very narrow bandwidth, increasing sensitivity. Receiver 316 may be a conventional AM or FM receiver.

In the UK, frequency bands available for telemetry and telecontrol are at 433.05-434.79MHz, 863.00-865.00MHz, 868.00-870.00MHz and 57MHz (for radio control). There is also a planned band at 403-404MHz. Most of these bands are limited to 10mW ERP. There is no technical reason why the command transmissions should be made within these frequency bands and alternative, legally-available frequencies may also be used.

Figure 4 shows a spread spectrum transmitter 26 for the tag of Figure 2. An oscillator 400 generates an rf carrier which is provided to a first terminal 406 of mixer 404, the output of which is coupled to antenna 28. PN code generator 402 generates a spread spectrum spreading code which is applied to a second terminal 408 of mixer 404. Switched power is indicted schematically by arrow 410.

The output of PN code generator 402 is arranged to move between binary signal levels of +1 and -1 so that when mixed with the output of oscillator 400 a binary phase shift keyed (BPSK) signal is provided to antenna 28. Mixer 404 is preferably a balanced mixer and may be constructed from a dual-gate FET or from a differential amplifier. Other forms of modulation such as differential BPSK and CPSM (continuous phase shift modulation) can also be used.

Oscillator 400 is preferably physically small and has a relatively low current consumption and power output. In general oscillator 400 may operate at any frequency, although the frequency should be high enough to allow modulation of the PN code sequence onto the carrier without excessive spectrum occupancy. In the UK the ISM (Industrial, Scientific and Medical) frequency band of 2.4-2.4835GHz is explicitly designated for spread spectrum transmissions provided these have an ERP of less than 10mW per 1MHz of spectrum occupancy. In the US additional frequency bands of 903-928MHz and 5.725-5.85GHz are also available for spread spectrum devices.

In the described embodiment oscillator 400 operates at about 2.4GHz and provides an output power in the range 1dBm to 10dBm. A small, low-power oscillator for these frequencies can be constructed using a ceramic resonator or a stub comprising a resonant length of solid coax. Mixer 404 preferably incorporates a buffer and impedance matching circuitry to optimise its coupling to antenna 28. Since a 1dBm transmitter output is sufficient to provide the necessary range for a cat locating tag, no amplification is necessary for this application. Where longer ranges are required, for example for tags for medium to large dogs, a monolithic microwave integrated circuit (MMIC) can be employed to boost the transmitted output to around 10dBm.

Referring to Figure 5 PN code generator 402 generates a pseudonoise spreading code as is know to those skilled in the art for spread spectrum use. Such codes are described in Spread Spectrum Communications Handbook by M.K. Simon, J.K. Omura, R.A. Scholtz and B.K. Levitt, McGraw Hill, 1994 and in Digital Communication with Fibre Optics and Satellite Application by H.B. Killen, Prentice Hall International, Inc., 1988. Since the tags operate according to a CDMA arrangement for distinguishing between signals simultaneously transmitted from multiple tags within range of a command transmission, the PN code is preferably adapted for such a CDMA system. Particularly suitable are Gold codes, as described in "Optimal binary sequences for spread spectrum multiplexing" by R. Gold, IEEE transactions on Information Theory, Vol.IT13, p.119-121, Oct. 1967, which is hereby incorporated by reference, and Kasami codes, described in "Cross-correlation properties of pseudorandom and related sequences" by D.V. Sarwate and M.B. Pursley, Proc. IEEE, Vol.68(5), p.593-619, May 1980, which is hereby incorporated by reference. Reference may also be made to the following, which are also incorporated by reference: CDMA - Principles of Spread Spectrum Communication by A.J. Viterbi, Addison-Wesley, 1995 and Digital Communications by J.G. Proakis, McGraw Hill International, 3/e 1995.

As is known to those skilled in the art, a PN code is a pseudorandom bit sequence with a strong autocorrelation at zero relative shift and a weak autocorrelation value elsewhere. Different PN sequences preferably have a low cross-correlation coefficient for both full

and partial overlap. The bits of a PN spreading code are often referred to as chips. With a chip clock of f_c and a spreading sequence of length N_c a PN code has a line spectrum with a line spacing of f_c/N_c and a $sinc^2$ envelope with nulls at $\pm f_c$.

A PN code may be generated by an n-stage shift register with EXOR (modulo-2 addition) feedback taps at specified positions. A simple PN code is a maximal length sequence or m-sequence, which has a length of $N_c = 2^n - 1$. Some exemplary shift register tap points are as follows:

No of stages (n)	Code length (N_c)	m-sequence tap points
6	63	[6,1] [6,5,2,1] [6,5,3,2]
7	127	[7,1] [7,3] [7,3,2,1] [7,4,3,2] [7,6,4,2] [7,6,3,1] [7,6,5,2] [7,6,5,4,2,1] [7,5,4,3,2,1]
8	255	[8,4,3,2] [8,6,5,3] [8,6,5,2] [8,5,3,1] [8,6,5,1] [8,7,6,1] [8,7,6,5,2,1] [8,6,4,3,2,1]
10	1023	[10,3] [10,8,3,2] [10,4,3,1] [10,8,5,1] [10,8,5,4] [10,9,4,1] [10,8,4,3] [10,5,3,2] [10,5,2,1] [10,9,4,2]

The taps can be reversed, that is a tap at a position I is substituted by a tap at a position (n-i), for additional sequences. Further tap points are given in Table 12 of the SX041, SX042, SX043 Users' Manual published by American Microsystems, Inc. of Idaho, USA which specific table is hereby incorporated by reference.

Gold codes are produced by modulo-2 addition of a "preferred pair" of two m-sequences generated by two shift registers with the same number, n, of stages. A Gold code has a length of $2^n - 1$ and a single preferred pair can be used to generate a set or family of $2^n - 1$ different Gold code sequences (plus the two basis m-sequences). Each Gold code of a family is produced by combining the m-sequences with a different relative time shift; since there are $2^n - 1$ possible time shifts there are $2^n - 1$ different Gold codes in a set. The large number of different Gold codes available makes them useful in CDMA

systems, although their autocorrelation functions are inferior to m-sequences. Gold code preferred pairs are listed in the paper by R. Gold mentioned above and in Tables 14 and 15 of the SX041, SX042, SX043 Users' Manual published by American Microsystems, Inc. of Idaho, USA. The specific Gold code preferred pairs listed are hereby incorporated by reference.

To avoid a dc component in the spread signal (which in the transmitted signal appears as a carrier spike) the codes are preferable "balanced", that is the number of 1's differs from the number of 0's by one. Balanced codes are obtained when an initial 1 of one of the m-sequences corresponds to an initial 0 in the other m-sequence.

The generation of Kasami sequences is described in the paper and other references mentioned above. A Kasami sequence is based upon a Gold code, with the modulo-2 addition of a further third m-sequence. The third m-sequence is obtained by decimation of one of the other two m-sequences, that is by taking every *q*th bit of the sequence and repeating the decimated *q* times. It can be shown that such a decimated sequence is itself an m-sequence of order n/2. Such codes are known as Kasami codes from the large set; a small set of Kasami codes is generated by combining a single m-sequence with its decimated version. An advantage of Kasami codes over Gold codes is the increased number of codes available for a CDMA system, the number of codes being $2^{n/2}(2^n + 1)$. Clearly n must be even. As with Gold codes, balanced Kasami codes are preferred and, if a subset of these is to be selected, it is preferable to choose those with the lowest full or partial cross-correlation.

The sets of Kasami codes listed in the above references are hereby specifically incorporated by reference into this specification. Further codes, also incorporated by reference, are listed in the PhD thesis of J.P.F. Glas in the library of Delft University of Technology, Delft, The Netherlands, and reference can also be made to "Selection of Gold and Kasami code sets for spread spectrum CDMA systems of limited numbers of users" by S.E. El-Khamy and A.S. Balamesh, International Journal of Satellite Communications, p.23-32, No.5, 1987.

Figure 5 shows a Kasami PN code generator 500. The generator comprises an oscillator 502 producing an output at the chip clock rate f_c to m-sequence generators 504, 506 and 508. Generator 508 produces a decimated version of the sequence from generator 504. The outputs of generators 506 and 508 are delayed by time delay elements 510 and 514 respectively, to allow a relative shift of the three m-sequences to generate a set of Kasami codes. The Kasami code generated depends upon the delays, in m-sequence bit or chip periods, introduced by these elements; it is assumed that the three m-sequence generators have a predetermined relationship between their sequences on start-up, for example all starting up in the all 1's state. The output from generator 504 and the delayed outputs from generators 506 and 508 are summed using EXOR elements 512 and 516 to produce the PN Kasami code.

Figure 5b shows how a programmable delay may be implemented using a set of AND gates 510 each with one input from a stage of a shift register of m-sequence generator 506 and a second input from a line or bus 511 on which a required delay is selected. The outputs of the AND gates are summed in EXOR gates 512.

Figure 5c shows an implementation of m-sequence generator 504 comprising a 6-stage shift register 504a with taps at the 1 and 6 positions combined in EXOR gate 504b and fed back the shift register's input. This generates a 63-bit m-sequence code. A set of Kasami codes for n = 6 may be generated using a preferred pair of shift register tap positions for m-sequence generators 504 and 506. Where generator 504 has taps at positions [6,1] and generator 506 has taps at positions [6,5,2,1], m-sequence generator 508 has a length n = 3 and taps at positions [3,2].

Figure 6 shows a second implementation of a Kasami PN code generator 600, with taps at these positions. The three m-sequence generators are, for consistency, denoted by the same reference numerals as in Figure 5a. In this embodiment the relative shift between the three m-sequence generators is achieved by loading the shift registers with a delayed version of the m-sequence at start-up. Effectively, each generator 504, 506, 508 starts at

a predetermined point in its sequence and two of the generators are arranged to provide the desired relative time delay to the third sequence. Thus in Figure 6, power-on-reset signal 604 is coupled to a load input (not shown) on each of the shift registers comprising code generators 504, 506 and 508. The data loaded into each shift register is determined by data input lines 602 which can be tied to ground or left open circuit (the lines have pull-ups which are not shown) to program the relative delay. If one of the generators starts at a predetermined point in its m-sequence, such as all 1's, a delay need only be programmed into the other two m-sequences (one of which is the decimated sequence).

The arrangement of Figure 6 can also be used to generate Gold codes by omitting the circuitry to the right of dashed line 606 or by setting PN generator 508 to all 0's. Kasami codes from the small set can be selected by omitting PN code generator 506 (or by setting its output to a continuous 0). The m-sequence of each individual generator can be obtained by setting the outputs of the other two generators to 0 or omitting these generators. The arrangement of Figure 6 simplifies manufacture as tags can be produced with a set of links 608 selected ones of which are broken, as shown at 610, to program a code for the tag.

In one embodiment oscillator 502 is a stable oscillator such as a crystal oscillator. This assists a spread spectrum receiver in the detector in keeping track of the PN code.

Figure 7 shows a spread spectrum transmitter in which a tag identity code is modulated onto the spreading code. Oscillator 702 generates an output at the chip frequency f_c for PN code generator 704. Code generator 704 preferably generates a Gold or Kasami code, but where the spreading code itself is not or is not on its own used for tag identification, the number of different CDMA codes available need only be sufficient to distinguish between signals from different tags stimulated to emit at the same time, and thus in one embodiment the code generator 704 generates a Gold code.

Data generator 708 has a clock input 712 derived from oscillator 702 by frequency division using divider 706. Driving the code generator 704 and data generator 708 from a single oscillator locks the two together and simplifies receiver design. The output of data generator 708 changes every code epoch and is combined with the output of PN code generator 704 by mixer (multiplier) 710. The code output by data generator 708 can be set by programmable or breakable links 714 in a similar manner to the PN code generator of Figure 6. Alternatively, the arrangement of Figure 7 can be implemented in software on a microprocessor, such as a microcontroller in the PIC12C5XX series available from Microchip Technology, Inc.

Figure 8 shows a spread spectrum code generator 800 which provides a predetermined bit sequence on start-up. Such a synchronising bit sequence can be used in conjunction with a matched filter at a spread spectrum receiver to reduce code acquisition time since the synchronising code allows the spreading code sequence in the receiver to be approximately locked to the transmitter so the only small relative adjustments of the two codes are necessary to achieve full lock.

Power on reset signal 802 is used to preset both the PN code generator 804 and sync sequence generator 806 in a predetermined phase relationship. As illustrated the power on reset signal 802 provides a rising edge after a time interval 803 from power 801 being applied to the chip oscillator (not shown). This allows the oscillator to settle before the receiver is synchronised.

As shown a signal 808 at the chip frequency f_c is applied to both the PN code generator 804 and the sync sequence generator 806. The output of one or other of these is selected by logic 812 in accordance with the output 814 of flip-flop 810. Power on reset signal 802 is applied to the D input of the flip-flop and sync sequence complete signal 816 resets the flip-flop so that code out signal 818 comprises first the sync sequence and then the PN code. Flip-flop 810 is clocked by chip clock 808 so that the selection of the PN code or sync sequence is synchronous with this clock. As shown, power on reset signal 802 should be high for a period longer than the sync sequence duration.

Figure 9 shows a battery monitor 30 for use with the tag 10. A switch 900 is used to place a load 902 across battery 24, at intervals determined by oscillator 908 and divider 906, for a period determined by monostable 904. Whilst the load is applied OR gate 910 controls switch 912 to apply power to level detect circuit 914, latch 916 and LED driver 918. If level detector 914 detects that the battery output is low, latch 916 and OR gate 910 operate to maintain power to LED driver 918. The low battery level detect signal is input to LED driver 918 through OR gate 920 which operates with latch 916 to maintain the input when a low battery level has been detected. The LED driver drives LED indicator 32 to flash the LED with a short on-long off duty cycle, such as 10%:90% on:off, to conserve power.

Figure 10 shows an example of a physical layout of components of a tag 1000 which is suitable for mounting on a cat's collar. The device is powered by a single button cell 1002, accessible via an opening closed by screw fitting 1004. The tag transmitter is coupled to a quarter wave antenna 1006 which can be fitted into the cat's collar; this forms one arm of an approximate dipole, the other arm of which comprises the tag components. The mixer/amplifier/matching circuitry is shown at 1008; if based on a dual-gate FET this may be relatively small. Oscillator 1010 is coupled to a ceramic or coaxial stub resonator 1012 to generate a 2.4GHz output.

Crystal oscillator and PN code circuitry 1014 may either comprise dedicated hardware or a microcontroller such as the 8-bit CMOS PIC12C508-04 8-pin SOIC (small outline IC) microcontroller from Microchip Technology Inc. Dedicated hardware may comprise surface mount or naked die components or a programmable gate array or an application specific IC (ASIC). The code generator is preferably driven by a crystal oscillator comprising crystal 1016. However, because the crystal is a relatively large component, it may be replaced by some other type of oscillator such as an RC oscillator, to save space, at the expense of a small reduction in tag detector sensitivity.

Audio circuitry 1018 is coupled to miniature microphone 1020 which is provided with an aperture 1022 on the exterior of the tag. Switch 1024 switches battery power to the code generator and oscillator/mixer.

At 2.4 GHz a quarter wave is approximately 3cm, which allows the construction of a tag having a length of 4-5cm, a width of approximately 1cm and a height of roughly ½cm (the width and height depend upon the size of button cell used). Conventional rf construction techniques may be employed; if miniaturisation is more important than cost the rf circuitry can be miniaturised by fabrication on silicon, which is offered as a service by American Microsystems, Inc. The tag housing may comprise metal, plastic or ceramic material, although for reasons of cost encapsulation in plastic, epoxy resin or similar is preferred. In a tag for a small dog the button cell can be replaced by an AAA size battery, or, for a larger dog by one or more AA batteries. Tags for larger animals also provide more space for, for example, an rf rather than audio command receiver.

Figure 11 shows, schematically, a physical layout for a tag 1100 suitable for tagging files, and at Figure 11b a side view of this tag. In Figure 11 like features to Figure 10 are denoted by like reference numerals. However, the tag has an rf command receiver 1102 coupled to aerial 1104. Likewise, the tag may operate at a higher frequency than the pet tag of Figure 10, with a correspondingly reduced length of resonator 1012 and aerial 1006. The tag 1100 is approximately rectangular and is designed to attach to the from of a file of papers, and hence a wide, flat profile is preferred for batteries 1106. These batteries may be accessed via a window 1108 having a sliding closure 1110 and a tape 1112 to assist removal of the batteries.

Figure 12 shows two alternative embodiments of a detector 1200, 1250 for the tag of Figure 2. The detector comprises a housing 1202, 1252 on which is mounted a directional Yagi aerial 1204. In the embodiment of Figure 12b the Yagi is hand held separately from the detector and plugs into a socket 1254. The detector also has a substantially omnidirectional aerial 1206,1256; the aerial in use is selected by switch 1208 or keyboard 1258 in the alternative embodiment.

The spreading code sequence is selected by thumbwheel switches 1210 and the encoded tag identity by a second set of thumbwheel switches 1212 (or, in the alternative embodiment, by keyboard 1258). Where a tag is identified solely by its spreading code switches 1212 may be omitted whilst switches 1210 may need to be augmented. Generally speaking, the functions provided by switches on the embodiment of Figure 12a are provided by keyboard 1258 in the alternative embodiment of Figure 12b. Likewise the display 1260 of Figure 12b serves in place of indicators described below on the embodiment of Figure 12a. Both detectors may be provided with an extendible rf aerial 1216, 1262 where they are being used with tags with rf command receivers. The embodiment of Figure 12a is designed to lie flat in the palm of a hand with Yagi aerial 1204 on top; the embodiment of Figure 12b is similar to a mobile phone.

Referring to Figure 12a, an on-off switch is provided at 1218, a command transmit button, where appropriate, at 1220, and a receiver lock reset button at 1222. Command transmit button 1220 may transmit an rf or an acoustic command, for example using a piezoelectric transducer. The detector is also provided with a detector test button 1224.

A received signal strength indicator is provided at 1214, a command transmit indicator at 1226 and a search/found indicator at 1228. In the case of an acoustic command transmission the command transmit indicator relies upon detecting an input at microphone 1230. An audible sounder 1232 (present but not shown in Figure 12b) supplements the visual search/found indicator 1228.

Figure 13 shows a block diagram for the tag detector of Figure 12a. The tag detector comprises a direct sequence spread spectrum (DSSS) receiver 1300 which receives an rf input 1301 selectable from antenna 1204 and 1206 by switch 1304 which operates to select one or other of preamplifiers 1306 and 1308, advantageously GaAs FET-based preamplifiers to provide a low receiver noise figure. The detector is controlled by microcontroller 1302 which interfaces to DSSS receiver 1300 via control lines 1310. The microcontroller also provides a control line 1305 to switch 1304 to select which

antenna receiver 1300 receives input from; the microcontroller receives an input from switch 1208 for antenna selection. Microcontroller 1302 also receives demodulated baseband data from data output 1312 of receiver 1300. A spread spectrum code acquisition/lock signal is also available to microcontroller 1302 on control lines 1310. Microcontroller 1302 may be any general purpose microcontroller such as a microcontroller in the 8051 family.

The microcontroller receives inputs from code switches 1210 and 1212 and transmit 1220, reset 1222 and test 1224 buttons. The code selection input includes information identifying a spreading code for the tag to be detected. In the case of a pet tag, a pet's owner will know this code as it will be provided with the tag when the tag is purchased. If lost, it may be determined electronically by, for example, using a tag detector to manually or automatically step through all possible codes. Similarly the tag identity data is also provided with the tag on purchase or, alternatively, this may be programmed into a tag after purchase by a user by, for example, making or breaking links within the tag as described above. Again, if this identity information is lost it may be read from the tag once the spreading code is known.

Where the tag does not include baseband (identity) data, for example, where tag identity is based purely on the tag's spreading code, data output 1312 from receiver 1300 is not required. In this case tag detection is ascertained on the basis of control information on lines 1310 indicating that a lock to a signal bearing the required spreading code has been achieved. The spreading code entered on switches 1210 is programmed into the receiver 1300 by the microcontroller via control lines 1310, typically into data registers in the receiver.

The microcontroller receives an input on line 1318 from a tone detector 1316 coupled to microphone 1230; the detector may be similar to the arrangement shown on Figure 3 for the tag. This allows the tag detector to determine when an acoustic command is issued to a tag and, when this command is inaudible, the microcontroller controls indicator 1226 and/or sounder 1232 to indicate the a command is issued. Since normally a tag

will only transmit for a predetermined time interval after receipt of a transmit command, at this point the microcontroller may, if necessary, reset spread spectrum receiver 1300 and cause search search/found indicator to flash, for example, yellow, to indicate a search mode during which time a tag transmission could be detected. If a tag transmission is detected the microcontroller causes indicator 1228 to indicate a tag has been found by, for example, displaying a green light and, in addition, sounder 1232 may also be caused to emit a tone.

In a detector for tags with rf command receivers, tone detector 1316 and microphone 1230 may be omitted. In this case, however, it is useful to incorporate command transmission means within the detector. The means may comprise transmit button 1220 which, when operated, causes command transmitter 1320 to transmit a command via aerial 1216. Button 1220 causes microcontroller 1302 to control transmission by means of transmitter control line 1314. Alternatively transmit button 1220 can control an acoustic sounder to issue an acoustic command to an acoustically commanded tag.

It is desirable to provide a reset function for the tag detector to reset the spread spectrum receiver 1300 and/or microcontroller 1302, to reset processors in these devices and/or to reset the receiver's spreading code search/acquisition process. It is also desirable to incorporate a test function within the detector, operated by test button 1224. In one embodiment this causes microcontroller 1302 to issue a command over line 1324 to an in-built tag 1322 to begin spread spectrum transmission. This tag may need to be shielded within the detector to avoid swamping the receiver/preamplifier input circuitry. When the test is invoked the spreading code for the test tag is programmed into receiver 1300 by microcontroller 1302 to allow the receiver to detect the tag and the search/found indicator 1228 then operates in the usual way. This allows a simple test of the entire detector circuitry. After the test microcontroller 1302 reprograms the receivers registers with the spreading code of the tag to be located. Other means for testing the detector will no doubt occur to the skilled person. Both the "reset" and "test" functions bolster user confidence in the system.

In use the detector is switched on and the spreading code and, if necessary, the tag identity code, for the tag to be located are entered by means of switches 1210 and 1212. Switch 1208 is operated to select the omnidirectional aerial and a command is issued to the tag to be located to transmit, either by blowing dog whistle 20 or by pressing transmit button 1220 on the tag detector. Transmit indicator 1226 then illuminates and search indicator 1228 flashes indicating that the system is searching for a spread spectrum transmission having the appropriate code. If no transmission is identified, indicator 1228 is extinguished. If a code lock is achieved and the correct tag identity is read indicator 1228 shows a steady green light and sounder 1232 indicates that the transmission from the desired tag has been detected. If a transmission with the correct spreading code but incorrect identity data has been received this does not necessarily indicate that the desired tag has not been found since there could be an error in the received data and/or interference from another tag having the same spreading code hence the detector displays a flashing green light using indicator 1228 and an intermittent tone on sounder 1232. Once a code lock has been achieved signal strength indicator 1214 gives an approximate indication of the received signal strength using, for example, red, amber and green indicators to indicate low, medium and high received signal strengths.

Once a code lock has been achieve the user changes from omnidirectional antenna 1206 to directional antenna 1204 and rotates the detector or, if separate, antenna, to locate the direction the transmission is coming from. The combination of transmission and signal strength can then be used to home in on the tag transmitting the signal and to distinguish between two tags transmitting from different places using the same spreading code. The user can also confirm whether or not the tag identity matches that required. Although microwave rf transmissions can sometimes give a misleading indication of the direction from which they originate, because of reflections from buildings and diffraction around obstacles, with time it is nevertheless possible to locate a transmitting tag.

Referring now to Figures 14 and 15, these show exemplary spread spectrum receivers for the detector of Figure 13. The skilled person will be aware that any conventional

spread spectrum receiver design could be used for the tag detector, providing that the receiver is suitable for spread spectrum transmission of the type emitted by the tag to be detected. In practice, it is likely that spread spectrum receiver 1300 will be based upon proprietary spread spectrum receiver integrated circuits, to reduce costs, although for reception of more specialised signals, such as those employing Kasami codes, a dedicated receiver design (albeit along conventional lines) may be necessary. For example, a spread spectrum receiver for Gold coded data can be implemented for well under £100 using the SX042 (S20042) and SX061 (S20061) ICs from American Microsystems, Inc. of Pocatello, Idaho, USA.

Figure 14 shows an rf front end 1400 for a spread spectrum receiver. This comprises an initial low noise amplifier 1402 followed by one or more IF stages 1404, a bandpass filter 1406 and, optionally, automatic gain control (AGC) circuitry 1408 having an AGC line 1410. The front end provides an output on line 1412.

The output 1412 from the rf front end 1400 may be used to feed a spread spectrum receiver as shown in Figure 15a or 15b. Referring to Figure 15a, which shows a conventional spread spectrum receiver design 1500, the input 1412 is mixed in mixer 1502 with the PN spreading code from code generator 1508 mixed with a signal from local oscillator 1506 in mixer 1504. The IF output of mixer 1502 is filtered by bandpass filter 1510. Thus the signal from local oscillator 1506 is BPSK modulated by the PN code and mixed with the incoming signal. If the PN code form generator 1508 has zero relative phase shift to the incoming spreading code there will be a correlation maximum in the mixed output; if the codes are different or not synchronised there will be a low correlation between them. Local oscillator 1506 is optional and input 1412 could be mixed with a "baseband" signal from PN code generator 1508, although this would be likely to introduce an unwanted dc component in the result.

The output of bandpass filter 1510 is mixed with quadrature signals from voltage controlled oscillator (VCO) 1518 and 90^0 phase splitter 1516. The outputs from mixers 1512 and 1514 are fed to integrate and dump filters 1522 and 1524 respectively and

thence to I and Q inputs of demodulator 1526 which demodulates the received (baseband) data and detects preamble and framing bits to output decoded data. Carrier tracking block 1520 receives inputs from the two integrate and dump filters to control VCO 1518. The carrier tracking circuitry also provides an AGC control output 1532 for AGC input 1410 of the receiver front end, to optimise the input on line 1412. The carrier tracking circuitry also provides a correlation value output on line 1534 which has a low level when the PN code generator 1508 is out of lock and a higher level when the code is synchronised to the incoming PN code; this signal can also be used as a measure of received signal strength. The correlation value output is fed to PN code track circuitry which controls VCO 1530 driving the PN code generator 1508. A second output 1536 from VCO 1530 controls data sampling in demodulator 1526.

Conceptually, the code from code generator 1508 slips past the code of the incoming signal until a correlation flash is detected on line 1534. At this point a tau-dither delay lock tracking loop comprising elements 1528, 1530 and 1508 in conjunction with the circuitry from input line 1412 to carrier tracker 1520, maintains the PN code from generator 1508 in synchronism with the received code. The amplitude of the IF output of mixer 1502 is a maximum when the generated code is synchronised to the received code and decreases to a low value when the codes are offset by one code chip or bit.

Frequently the circuitry to the right of dashed line 1538 is implemented digitally, either in software on a digital signal processor (DSP), or in dedicated hardware. In such cases the output from IF bandpass filter 1510 is quadrature sampled by analogue-to-digital converters (A/Ds) to generate digital I and Q signals. AGC output 1532 is then used to optimise incoming signal quantisation. The A/D sampling frequency should be greater than 2fc; in some applications the A/D sampling frequency may be chosen to be an integer multiple of the IF centre frequency to “fold back” the signal to dc.

Figure 15b shows another example of a digital spread spectrum receiver 1600 in which an input on line 1412 is mixed with quadrature signals from oscillator 1602 and 90^0 phase splitter 1604 in mixers 1606 and 1608 to generate I and Q signals 1610 and 1612

for A/Ds 1614. The remainder of the processing is done digitally, digital I and Q signals 1620 and 1622 being fed to Nyquist filters 1624 and 1626 and thence to matched filters 1628 and 1630 which are configured to provide a maximum output when the desired PN code input is received. The matched filter outputs feed bit synchronisation circuitry 1632 which provides an error signal 1634 to delay locked loop 1636 which provides sample clocks 1618 to ADCs 1614. The sample clocks are preferably controlled to sample at the mid point of a chip. A second output 1638 from the bit synchronisation circuitry feeds demodulator 1634 to provide a baseband data output 1640.

Both this receiver and the receiver of Figure 15a are configured for serial code acquisition. Receiver acquisition time, $T_{acq} \approx 4.N_c.T_c.N_c$ where N_c is the number of chips in the spreading sequence and T_c the chip period. The factor of 4 arises because the receiver typically slips every other epoch (i.e. complete code sequence) and when it slips, it slips only half a chip period. The final N_c arises because all chips in the code are matched before the code slips.

The acquisition time can be adjusted slightly by adjusting loop filter parameters. It can be reduced significantly by performing only a partial correlation before the code slips, for example, if only 10% of the chips are correlated T_{acq} is reduced by a factor of 10. The practicality of this depends upon the codes used and interference. Another strategy for decreasing lock time is to employ a combination of serial and parallel code acquisition by, for example, using more than one pair of matched filters in the arrangement of Figure 15b, the pairs of matched filters being chosen to respond to codes of different relative phases. Thus, for example, by providing two pairs of matched filters T_{acq} can be halved. To further reduce the acquisition time a synchronisation sequence may be transmitted by the tag on start-up which is detected by a corresponding matched filter in the receiver to provide an approximate initial code lock.

Some examples of system design will now be described. A system suitable for cats and small dogs has a carrier frequency of approximately 2.4GHz, in the ISM band allocated

for spread spectrum transmissions. A chip frequency of f_c = 127Kbps drives a Gold code generator with 7 stage shift registers whereby n = 7 and N_c = 127. There are therefore 127 Gold code sequences generated by each preferred pair of taps and there are four preferred pairs: [7,1] and [7,4,3,2]; [7,1] and [7,6,5,2]; and [7,1] and [7,3,2,1]; [7,3,2,1] and [7,6,5,2]. These parameters result in an acquisition time $T_{acq} \approx 0.5$ secs.

The preferred pair [7,1] and [7,3,2,1] provides 37 balanced codes and in total the four sets of preferred pairs provide at least 80 balanced codes. This is sufficient for a short range system to ensure that it is unlikely that two tags stimulated simultaneously by a command transmitter have the same spreading code. With 84 balanced codes the chance of three simultaneously transmitting tags having the same code is (83/84).(82/84) = 0.96, i.e. there is approximately a 4% chance that two of the tags will share the same spreading code. Eleven tags must be stimulated to transmit simultaneously before there is an even chance that two share a code. This is sufficient codes to ensure an acceptable risk of "collision" for the shorter range command transmitters used with tags for cats and small dogs.

To identify a cat or dog with baseband data. The transmitted data comprises a preamble sequence such as all 1's or all 0's to provide a stable code to which the receiver can lock. The preamble length should approximate to the receiver acquisition time, and thus in the above embodiment would comprise 508 bits. The transmitted tag identity data is framed by start and stop sequences, for example hex codes FC and F0.

A six digit identity code, providing one million differently numbered tags may be contained in three baseband data bytes. This chip rate allows the coded baseband data to be generated by a microcontroller such as a PIC12C5XX series controller operating at 4MHz. This provides 32 instruction cycles per chip and each instruction, except for branch instructions, takes a single cycle, allowing a 30 instruction loop. The manufacturers of this device also offer serialised quick-turnaround production programming services in which most data is factory programmed except for a small

number of user-defined location for storing an identity number. Furthermore, these devices will operate at 2.5 volts and can be obtained for ~ US$1, in quantity.

The range over which over which a transmission from the above-described tag can be received may be estimated as follows. The null-to-null bandwidth of the DSSS spread spectrum signal is $2f_c$ = 254KHz, and the 3dB bandwidth ≈ 0.88 x 254KHz = 224KHz. At 290K the noise power in the receiver, P_N = -174 + 10log(bandwidth) ≈ -120dBm. The processing gain of the receiver, G_p = 10log(spread bandwidth/baseband bandwidth), and ≈ 20dB. For a 10dB output signal to noise ratio, 2dB receiver processing losses (in the tau-dither delay lock loop), and a 4dB receiver noise figure, the required input signal to noise ratio is -4dB. Thus the receiver sensitivity is -124dBm (for an omnidirectional aerial).

Assuming a transmitter output of approximately 1mW, antenna gain (for a dipole) and coupling losses roughly cancel out so that transmitter ERP ≈ 1dBm. Thus a path loss of approximately 123dB may be tolerated. In free space at 2.4GHz the path loss is approximately 100dB at a range of 1km and changes by 20dB for a 10:1 range change. The free space range is thus approximately 10km. In an urban environment, the path loss P_L(in dB) ≈ 40 + 35log(d in metres) where d is the range. This gives an urban range of approximately 230m; indoors a range of >100m is expected. It can be seen that with an acoustic command transmitter the command transmitter range will dominate; the same is not necessarily true in a system with an rf command transmitter and tag command receiver.

A directional Yagi antenna can provide an extra 10-15dB of gain and for greater range the transmit power may be increased to 5mW (+7dBm) and the receiver noise figure reduced to approximately 2dB. This provides an additional 15-20dB of tolerable path loss which corresponds to a 100km line of sight range and a 600-900m urban range. The processing gain increases by roughly 3dB for each additional shift register stage so that using a 10 stage shift register (N_c = 1023) will provide a further 9dB of processing gain, increasing the urban range to 1.5-2km.

In a system with a greater range the chance of "collision" between tags having the same spreading code is increased and thus a system employing a greater number of codes is preferable. A system with $n = 8$, $N_c = 255$ and $f_c = 511$KHz leaves T_{acq} unchanged. The higher f_c can be provided using a 20MHz PIC device such as a PIC16C662A-04/SP or a PIC16C715-201, both of which are available at low cost in a 28 pin SOIC package.

This arrangement approximately doubles the number of balanced codes available, as well as providing a 3dB greater processing gain and thus an improved transmitter range. Gold code preferred pairs for $n = 8$ include [8,6,5,3] and [8,6,5,2]; [8,6,5,2] and [8,7,6,5,2,1]. Longer shift register sequences may be used without compromising the acquisition time by, for example, storing an initial synchronisation sequence for the receiver in the PIC ROM.

Generally speaking there is a trade off between f_c and cost, a greater f_c requiring a more costly receiver, as well as between f_c and number of codes/acquisition time/collision chance. Acquisition time increases as N_c^2 and also varies as $1/f_c$. Thus with $f_c = 1$MHz and $N_c = 1023$ the acquisition time is approximately 4 seconds, although there is 30dB processing gain, providing the tag with a much greater range, and approximately 1000 balanced codes available. Gold code preferred pairs for $n = 10$ include [10,3] and [10,5,3,2]; [10,3] and [10,9,4,1]. To decrease the acquisition time to a more practical level such as 1 second, f_c may be increased to 4MHz, or four parallel pairs of matched filters may be used in the receiver, or a partial correlation of ~25% of the code's chips, rather than 100%, may be applied in the code slip loop.

In another embodiment a tag has the same or similar parameters ($N_c = 1023$) but employs Kasami codes rather than Gold codes. Thus for $n = 10$, there are approximately 32K codes for each Gold code preferred pair of which ~10K are balanced codes. This allows a tag to be identified merely on the basis of its spreading code and there is thus no need to modulate the code with additional baseband data. Likewise, at the detector, there is on need to demodulate baseband data as confirmation that the tag with the

desired code has been located is provided by the code lock signal alone. This simplifies both tag and receiver design (and obviates the need for a microcontroller within the tag) as well as reducing the chance of collision between two identical codes. Also the simplified hardware facilitates a higher f_c thus more easily providing a practical code acquisition time with longer codes.

A Kasami code-based system is thus particularly advantageous where longer transmit and receive ranges make collisions more likely, such as when tagging larger dogs which can stray considerable distances. Another application where tags with Kasami codes are useful is in lost file location. Generally speaking files are stored in groups and thus transmissions from a plurality of tagged files in roughly the same vicinity are likely to be triggered simultaneously. The use of Kasami codes assists in distinguishing amongst transmissions from such tagged files. As with a tag for pets, a tag for files may use either an acoustic or an rf command receiver.

In one embodiment of a file tracking system a plurality of detectors are networked, using either wireless or wired connections, to a central controller. Such a network may operate over an existing intranet or internet communications system. Physically the detectors are located adjacent groups of files, for example, in a file store and/or in selected rooms and/or in filing cabinets. With such an arrangement a lost file can be localised from the central controller by interrogating each of the detectors either in series or in parallel until the tag with the correct code/identity is located. A manual or detector-assisted search can then be used to identify the precise location of the tagged file. A similar arrangement based on a wide area network (WAN) can be used to determine the approximate location of a lost pet from a central control terminal. In the case of file location a centralised command transmitter may be sufficient for an entire building or the central control unit may send a signal to each detector to transmit a command to its local tags to transmit; this latter arrangement is preferred for locating tagged pets.

Referring now to Figure 16, this shows a homodyne radar-based tag detector 1650, in use for locating a tagged file 1652. The detector illuminates the tag 1660 using transmit horn antenna 1654 and receives a modulated spread spectrum return at horn antenna 1656. For isolation the transmit and receive antennas are preferably on opposite sides of the detector and for convenience in use a pistol-type grip 1658 may be provided.

Figure 17a shows a block diagram of tag 1660. The command receiver 1662 and its antenna 1664, battery 1666, switch 1668, chip oscillator 1670 and PN code generator 1672 are similar to those described earlier with reference to figures 2 to 6. Oscillator 1670 is preferably a crystal oscillator. The PN code generator preferably generates a Kasami code unmodulated by baseband data; oscillator 1670 preferably operates at a high frequency than is preferred for a pet tag, such as $f_c \geq 20$MHz, ≥ 70MHz, or ≥ 100MHz. Again switch 1668 switches power to oscillator 1670 and PN code generator 1672 and, if necessary, also to modulator 1674. The output of PN code generator 1672 drives modulator 1674 coupled to dipole 1676. This modulates the reflected signal from the radar providing a spread spectrum coded return signal.

Use of a higher f_c allows longer code sequences for a given acquisition time and hence a greater number of different codes, reducing the collision risk. This is important as it may be necessary to distinguish amongst 10,000 or 100,000 different files stored in large groups. The increased processing gain is also helpful in a radar system where the return signal is often very low level.

Figure 17b shows an alternative embodiment in which the output of code generator 1672 is mixed with baseband data 1680 in mixer 1678 before input to modulator 1674; this allows baseband data to be modulated onto the radar return if desired. As before, the code and baseband data are preferably synchronised.

Figures 17c and d show, conceptually, methods for phase modulation of the code onto the radar return. In Figure 17c the incoming signal incident on the tag is mixed with the PN code in dual-gate FET 1678 which drives one arm of dipole 1676 (biasing is not

shown). Amplifier 1680 is arranged to drive one gate of FET 1678 with a signal in phase with the incoming radiation.

In Figure 17d dipole 1676 is replaced by separate receive 1682 and "transmit" 1684 antennas. The incoming radar signal is amplified in amplifier 1686, mixed with the PN code in mixer 1688 and fed via amplifier 1690 to transmit antenna 1684 which provides a radar return signal.

Figures 17c and d are intended to provide phase modulation of the radar return. For amplitude modulation of the radar return modulator 1674 may simply present a changing load to dipole antennas 1676 and may comprise, for example, a switch which shorts or leaves open circuit dipole arms 1676, according to whether the output of the PN code generator is a one or a zero.

The tag of Figure 17a may be self-powered, in which case battery 1666, receiver 1662, antenna 1664 and switch 1668 are no longer needed. In a self -powered embodiment power is derived from the incident rf signal from the interrogating radar, as shown conceptually in Figure 17e. Here receive antenna 1692 and (optional) bandpass filter 1694 collect rf energy from the incident radar radiation for rectification by diode 1696, preferably a low-bias Schottky diode, and smoothing by capacitor 1698, to provide an approximate dc power output to the tag oscillator and code generator. Since only limited power is available, depending upon the level of received energy from the rf radar transmission it may not be practical to use a crystal oscillator for oscillator 1670 and an alternative, lower power oscillator, such as a CMOS RC oscillator may be preferred.

Figure 18 shows a physical embodiment of the tag of Figure 17a, using the same reference numerals. The tag has a broad, low-profile configuration for secure attachment to a file and to reduce interference with physically adjacent files. Likewise batteries 1666 preferably have a low height.

Figure 19 shows a radar detector for the tag of Figures 17 and 18. Figure 19a shows a homodyne radar front end 1900 and Figure 19b shows a spread spectrum receiver 1950 to which it is coupled. In Figure 19a an unmodulated rf carrier is generated by oscillator 1902, in an exemplary embodiment at 10.7GHz, and amplified by power amplifier 1904 before transmission by antenna 1654. Antenna 1654 is preferably a high gain, directional antenna such as a horn antenna; an antenna with open end dimension of 3λ by $3\lambda/2$ (where λ is the wavelength of the rf carrier) provides a gain of 16.5dBi, and at 10.7GHz, $\lambda/2 \approx 1.4$cm.

The return signal from tag 1660 is received at antenna 1656, preferably a high gain horn antenna, amplified by low noise block downconverter 1906 and low noise preamplifier 1908 before being mixed with the original carrier from oscillator 1902 in mixer 1910. The output of mixer 1910, which is at baseband, is low-pass filtered by filter 1912, which rolls off at approximately f_c, and is high-pass filtered by filter 1914 to remove the large dc component produced by unmodulated carrier. The spectrum of a spread spectrum signal is a line spectrum with spacing f_c/N_c and filter 1914 should have a sharp roll-off below the lowest frequency component in the spread return. The spread spectrum coded signal, at dc, is provided on output 1916.

The output of the radar front end may be fed to a conventional DSSS receiver if tag 1660 provides a phase modulated return. Since the output 1916 is at dc in-phase and quadrature sampling of the signal is necessary to identify positive and negative frequency components. Since phase modulation by tag 1660 is relatively inefficient, it is more likely that in a practical system the spread system code is amplitude modulated onto the radar return. In this case a simplified receiver design, such as is outlined in Figure 19b, may be used with AM detection, to correlate with the received code and/or recover any baseband data.

In Figure 19b input 1951 is coupled to output 1916 of the rf front end and provides a first input to correlator 1952. The correlator has a second input from PN code generator 1954 and, conceptually, the PN code from generator 1954 is controlled to slip past the

code modulating the radar return until a correlation flash is identified, when the code generator 1954 is locked to the input code. This is achieved by demodulator 1956, code tracking circuitry 1958 and code VCO 1960. An output 1964 from tracking circuitry 1958 indicates code lock and, if necessary, baseband data is provided on output 1962 from demodulator 1956. Preferably receiver 1950 is implemented digitally, either in hardware, or in software on a DSP; in this case, output 1916 of rf front end 1900 is digitised by one or more analogue to digital converters, if necessary controlled to take account of any residual dc offset.

A homodyne radar-based system is particularly practical for file location because in general only short range tag detection is required and hence a low level return signal can be tolerated. Use of a homodyne radar removed the need for an rf carrier oscillator in the tag and may allow the illuminating radiation to be used as the tag's power source, thus providing smaller and cheaper tags. A cheap embodiment of a tag uses the parameters outlined above for file tagging ($N_c = 1023$, $f_c \sim$ 4-6MHz for $T_{acq} \approx$ 1-0.7 seconds). The command receiver may be acoustic or rf (at its simplest, a tuned circuit for carrier detection).

In a second embodiment a tag for locating files has a Kasami PN code generator based on 12-stage shift registers ($n = 12$, $N_c = 4095$, 256K codes). This provides $\sim 10^5$ balanced codes for tagging large numbers of files with a low risk of collision and without the need for baseband identity data; this also provides a processing gain of $\sim$ 36dB. At $f_c \sim$ 70MHz, $T_{acq} \sim$ 1 second; at $f_c \sim$ 100MHz, $T_{acq} \sim$ 0.7 seconds. For a low cost Kasami code generator operating at 70MHz may be provided by a field programmable gate array (FPGA) such as an XC3020 from Xilinx; when operating at higher frequencies an AT60XX from Atmel may be used. At 70MHz the spread spectrum line spacing is 17KHz, at 100MHz it is approximately 24KHz and the high pass filter 1914 of the rf front end should be chosen to roll off steeply below these frequencies, as appropriate.

No doubt many effective alternatives will occur to the skilled person and it should be understood that the invention is not limited to the described embodiments. For example, the tags have been described mainly in connection with direct sequence spread spectrum transmissions but a frequency hopping spread spectrum transmitter, such as the GJRF-XX IC from Gran-Jansen, Oslo, Norway, can also be used in a tag.

CLAIMS:

1. A tag for locating an object, the tag comprising:

an rf transmitter to transmit a coded signal; and

an acoustic command receiver to receive an acoustic command; and

wherein the coded signal is transmitted in response to reception of an acoustic command.

2. A tag as claimed in claim 1 wherein the coded signal is a spread spectrum signal having a spreading sequence code.

3. A tag as claimed in claim 2 wherein the rf transmitter is a direct sequence spread spectrum transmitter.

4. A tag as claimed in claim 3 wherein the spreading sequence comprises a Gold code.

5. A tag as claimed in claim 3 wherein the spreading sequence comprises a Kasami code.

6. A tag as claimed in claim 4 or 5 wherein the length of the spreading sequence is $\leq 2^{10}$ - 1 chips, and preferably $\leq 2^8$ - 1 chips.

7. A tag as claimed in claim 4, 5 or 6 wherein the spread spectrum signal comprises the spreading sequence code modulated by baseband data.

8. A tag as claimed in claim 7 wherein a tag identity comprises a combination of the spreading sequence code and the baseband data.

9. A tag as claimed in claim 5 wherein the spreading sequence code is unmodulated by baseband data.

10. A tag as claimed in claim 9 wherein the length of the spreading sequence is $\leq 2^{12}$ - 1 chips, and preferably $\leq 2^{10}$ - 1 chips.

11. A tag as claimed in any preceding claim wherein the command receiver is configured to control a power supply to at least part of the tag.

12. A tag as claimed in claim 11 wherein the command receiver controls a power supply to the transmitter for transmitting the coded signal and for ending the transmission after a time interval, or on cessation of the command, or on receipt of a stop command.

13. A tag as claimed in any preceding claim wherein the command receiver is responsive to acoustic commands at a frequency of $\geq$ 5KHz, preferably $\geq$ 10KHz, more preferably $\geq$ 15KHz, still more preferably $\geq$ 17KHz, and most preferably $\geq$ 20KHz.

14. A tag as claimed in any one of claims 1 to 12 wherein the command transmitter is responsive to acoustic commands which are substantially inaudible to most adult humans.

15. A tag as claimed in claim 13 or 14 wherein the command receiver comprises an acoustic transducer coupled to a tone detector.

16. A tag for locating an object, the tag comprising:

a command receiver to receive a command; and

a spread spectrum rf transmitter, the spread spectrum transmitter having a spreading code;

wherein the transmitter transmits a spread spectrum signal responsive to a received command; and

wherein the transmitted signal conveys the spreading code unmodulated by baseband data.

17. A tag as claimed in claim 16 wherein identity data for the tag consists of the spread spectrum spreading code.

18. A tag as claimed in claim 16 wherein the tag transmits only the spreading code.

19. A tag as claimed in claim 16, 17 or 18 wherein the spreading code comprises a Gold code.

20. A tag as claimed in claim 16, 17 or 18 wherein the spreading code comprises a Kasami code.

21. A tag as claimed in any one of claims 16 to 20 wherein the transmitter is a direct sequence spread spectrum transmitter.

22. A tag as claimed in any one of claims 16 to 21 wherein the length of the spreading sequence is $\leq 2^{14} - 1$, and preferably $\leq 2^{12} - 1$.

23. A tag as claimed in any one of claims 16 to 22 wherein the command receiver includes an acoustic transducer and is responsive to acoustic commands.

24. A tag as claimed in claim 23 wherein the command receiver is responsive to acoustic commands which are substantially inaudible to adult humans.

25. A tag as claimed in any one of claims 16 to 24 wherein the command receiver controls a power supply to the transmitter to switch transmission on.

26. A tag as claimed in claim 25 further comprising means to switch transmission off after a predetermined interval.

27. A tag as claimed in any preceding claim further comprising means to collect and store solar power.

28. A tag as claimed in any preceding claim further comprising a battery for powering the tag.

29. A tag as claimed in claim 28 further comprising a battery monitor for indicating when battery power is low.

30. A tag as claimed in claim 29 wherein the battery monitor comprises an indicator with an on-off duty cycle in which the on period is less than the off period.

31. A tag as claimed in claim 29 or 30 wherein the battery monitor is configured to periodically put the battery under load to test the battery.

32. A set of tags, each tag as claimed in any one of claims 4 to 31, each tag having a different spreading sequence.

33. A set of tags as claimed in claim 32 wherein the Gold or Kasami codes are generated by means of shift registers with feedback taps and wherein the codes are based upon more than one preferred pair of shift register taps.

34. A detector for locating the tag or set of tags of any preceding claim.

35. A detector for locating an object having a tag, the detector comprising:

a direct sequence spread spectrum (DSSS) receiver for receiving from the tag a spread spectrum signal based on a Gold or Kasami code;

a first aerial coupled to the receiver;

input means for user selection of a said Gold or Kasami code; and

indicating means for indicating when a tag with the selected code is detected.

36. A detector as claimed in claim 35 further comprising input means for user input of tag identity data and wherein the or another indicating means indicates when a tag with both the selected code and the user-input tag identity is detected.

37. A detector as claimed in claim 36 further comprising means to indicate when a tag with the selected code and identity data different to the user-input tag identity is detected.

38. A detector as claimed in claim 35 wherein the DSSS receiver is configured to receive a spread spectrum signal unmodulated by baseband data and wherein a tag for detection is identified by said unmodulated Gold or Kasami code.

39. A detector as claimed in any one of claims 35 to 38 further comprising a second aerial, the first and second aerials having different directionality, and means for selectively coupling either the first or the second aerial to the receiver.

40. A detector as claimed in any one of claims 35 to 39 further comprising an acoustic transducer and means coupled to the acoustic transducer to indicate the issue of an acoustic command signal for commanding a tag.

41. A detector as claimed in any one of claims 35 to 40 further comprising means to issue an acoustic command signal to a tag.

42. A detector as claimed in any one of claims 35 to 39 further comprising means to issue an rf command signal to a tag.

43. A detector as claimed in any one of claims 35 to 42 wherein the detector comprises control means for searching or indicating a search for the tagged object substantially only when a tag is likely to be transmitting.

44. A detector as claimed in any one of claims 35 to 43 further comprising test transmission means for transmitting a test transmission for testing operation of the detector.

45. Use of the tag or set of tags of any one of claims 1 to 33 for locating mammals.

46. Use of the detector of any one of claims 34 to 44 for locating mammals.

47. A tag for use with a tag detector radar, the tag comprising:

a pseudonoise (PN) code generator for generating a spreading code for a spread spectrum system; and

a modulator and antenna combination for providing a modulated radar return from the tag;

wherein the PN code generator is coupled to the modulator for modulating the radar return with the spreading code.

48. A tag as claimed in claim 47 wherein the modulator comprises means to phase modulate the spreading code onto the radar return.

49. A tag as claimed in claim 47 or 48 comprising mixing means to mix an incident radar signal with the PN code to modulate the spreading code onto the radar return.

50. A tag as claimed in claim 47 wherein the modulator comprises amplitude modulation means to amplitude modulate the spreading code onto the radar return.

51. A tag as claimed in claim 47 or 50 wherein the modulator comprises switch means coupled to the code generator and to the antenna to modulate the radar return with the spreading code.

52. A tag as claimed in claim 51 wherein the antenna approximates a dipole and wherein the switch means is coupled between arms of the dipole.

53. A tag as claimed in any one of claims 47 to 52 wherein the code is selected from an m-sequence and/or a Gold code and/or a Kasami code.

54. A tag as claimed in any one of claims 47 to 53 further comprising means to modulate the PN code with baseband data.

55. A tag as claimed in any one of claims 47 to 54 further comprising a command receiver to control operation of the PN code generator and/or modulator.

56. A tag as claimed in claim 55 wherein the command receiver is an rf receiver.

57. A tag as claimed in claim 56 wherein the command receiver comprises an acoustic command receiver.

58. A tag as claimed in any one of claims 47 to 57 further comprising means to at least partially power the tag using incident radar radiation.

59. A set of tags each as claimed in any one of claims 47 to 58, each having a spreading code with a high autocorrelation coefficient and a low cross-correlation coefficient with the codes of other tags in the set.

60. A radar detector for the tag or set of tags of any one of claims 47 to 59.

61. A radar detector for a tag providing a radar return modulated with a spread spectrum code, the detector comprising a radar front end coupled to a spread spectrum receiver.

62. A radar detector as claimed in claim 61 wherein the radar is a homodyne radar.

63. A radar detector as claimed in claim 61 or 62 wherein the receiver is adapted for reception of a phase modulated spread spectrum signal.

64. A radar detector as claimed in claim 61 or 62 wherein the receiver is adapted for reception of an amplitude modulated return signal.

65. Use of the tag or set of tags or detector of any one of claims 47 to 64 for detecting one of a plurality of tagged objects which are simultaneously illuminated by an interrogation signal.

66. Use of the tag or set of tags or detector as claimed in claim 65 for detection at relatively short range, particularly <10m, more particularly <3m.

67. Use of the tag or set of tags or detector as claimed in claim 65 or 66 for locating a lost file.

68. A network comprising a plurality of tag detectors, each as claimed in any of claims 34 to 44 and 60 to 64, coupled of couplable to a central control unit for providing an approximate tag location.

69. System for detecting a tagged object comprising a tag or set of tags as claimed in any one of claims 1 to 33 and 47 to 59, and a detector set of detectors as claimed in any one of claims 34 to 44, 60 to 64 and 68.

ABSTRACT:

A tag (10) for locating an object, the tag comprising: an rf transmitter (26) to transmit a spread spectrum signal such as a Gold or Kasami coded signal; and an acoustic command receiver (20) to receive an acoustic command; and wherein the coded signal is transmitted in response to reception of an acoustic command.

A corresponding detector (1200) for locating an object having the tag comprises: a direct sequence spread spectrum (DSSS) receiver (1300) for receiving from the tag a spread spectrum signal based on a Gold or Kasami code; a first aerial (1206) coupled to the receiver; input means (1210) for user selection of a said Gold or Kasami code; and indicating means (1228) for indicating when a tag with the selected code is detected.

The system is useful for locating lost pets.

Figure 2.

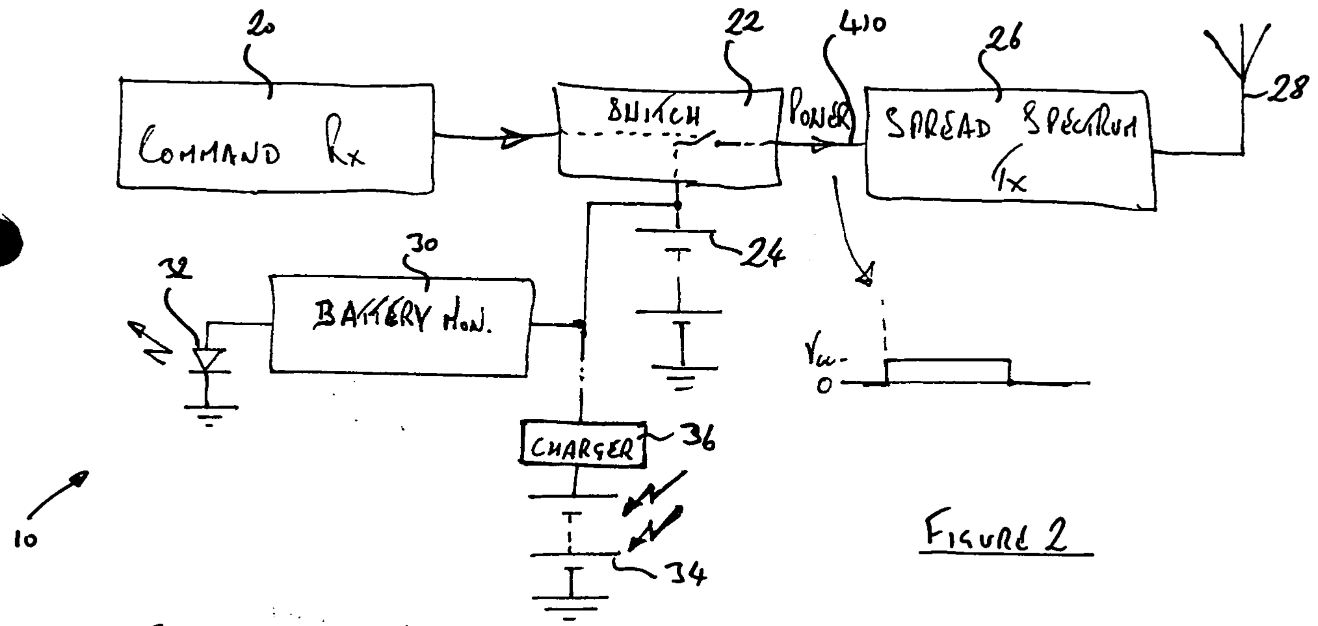


FIGURE 2

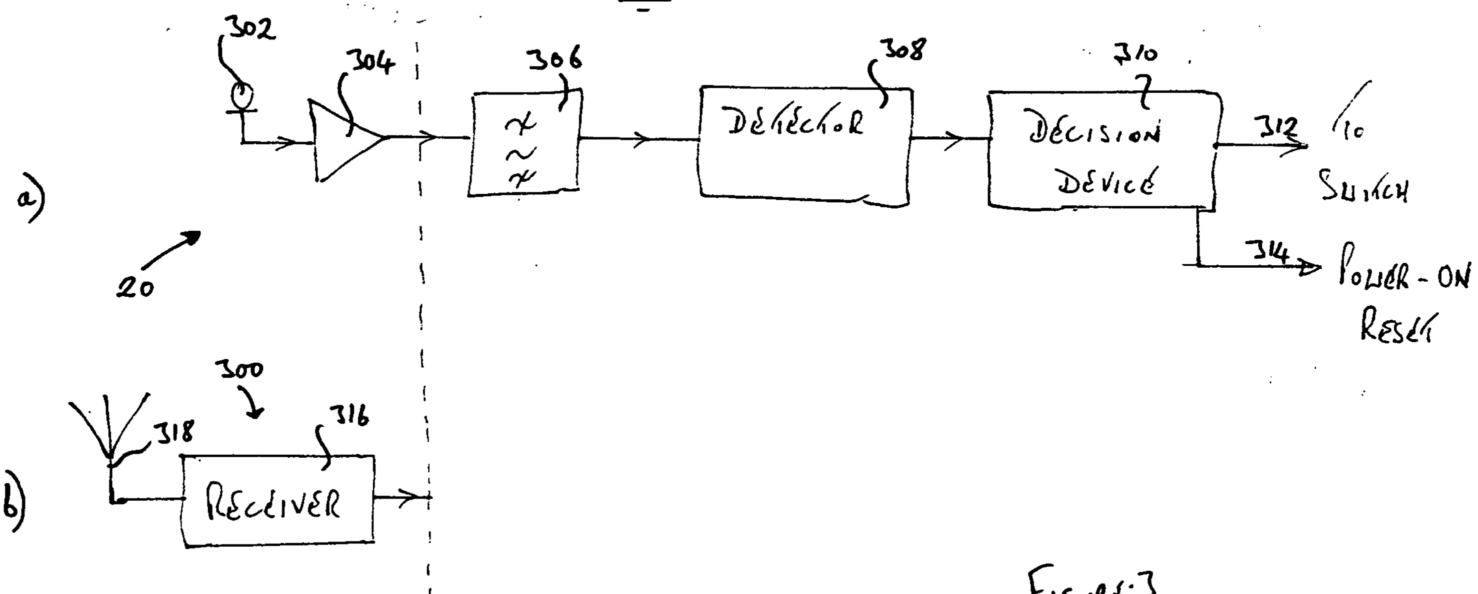


FIGURE 3

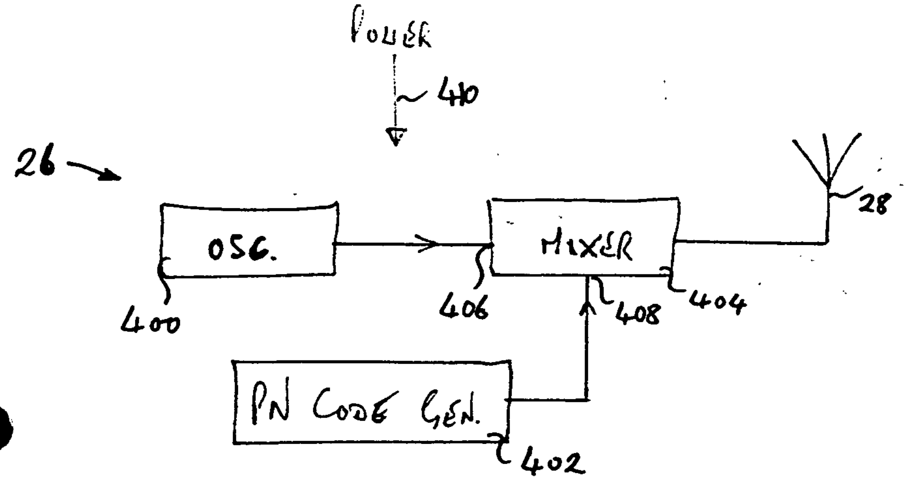


FIGURE 4

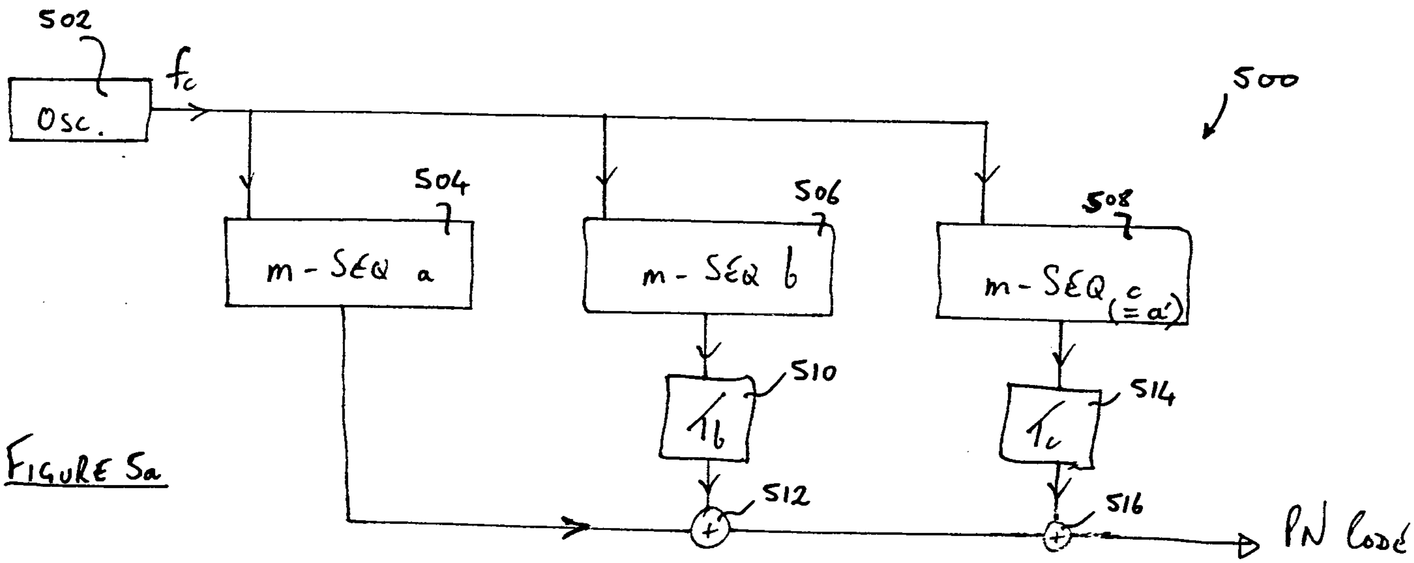
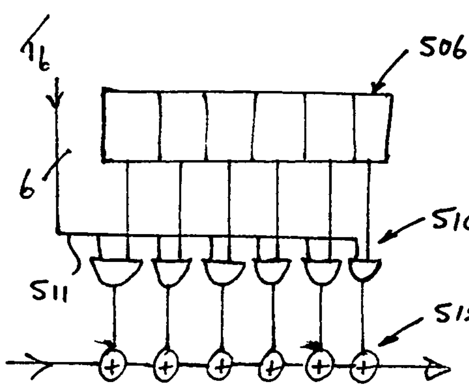
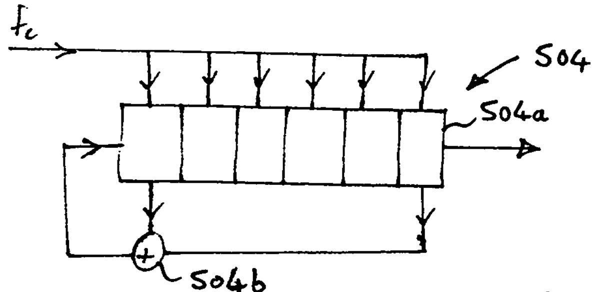


FIGURE 5a





m[6, 1]

FIGURE 5c

Gold preferred pair : m[6, 1] a   Kasami : m[3, 2] c

m[6, 5, 2, 1] b   n = 3

FIGURE 5b

n = 6

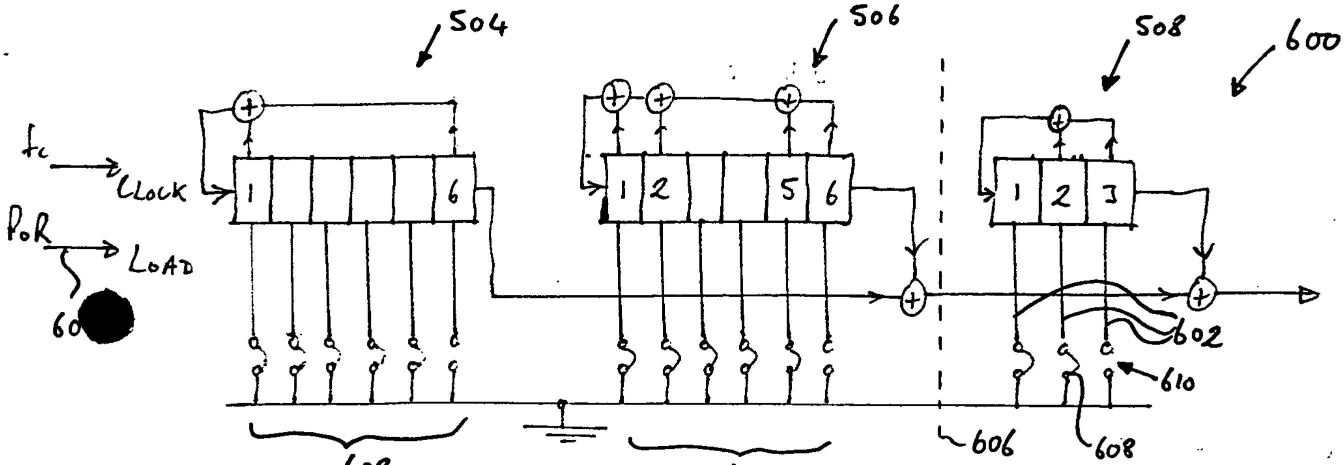


FIGURE 6

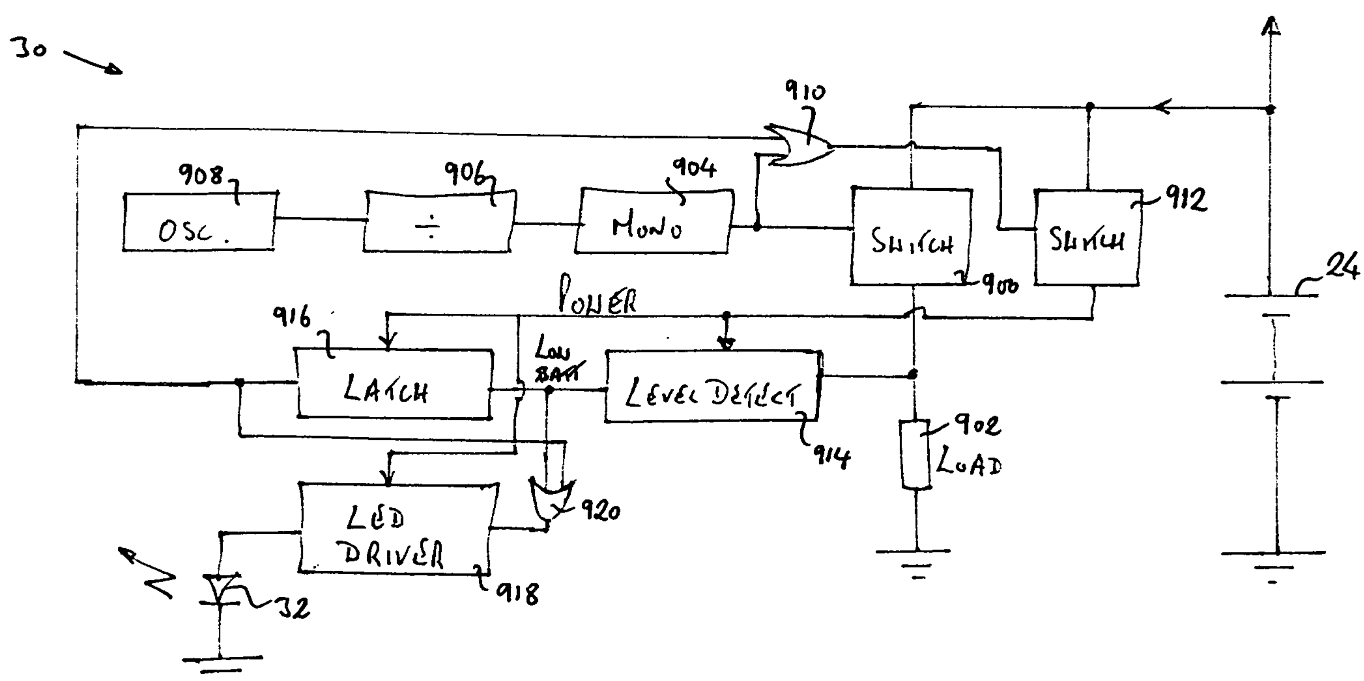


FIGURE 9

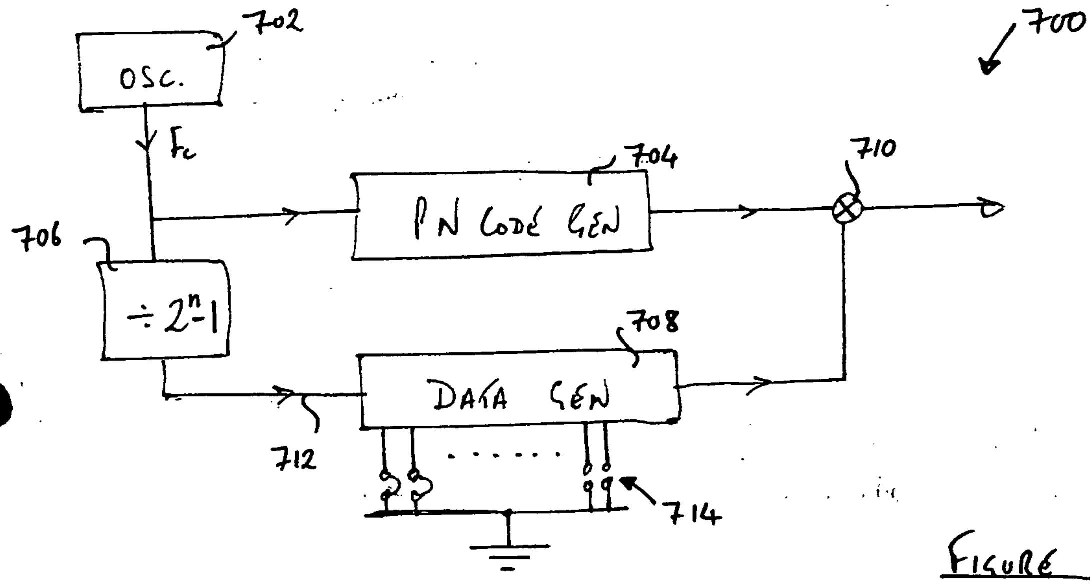


FIGURE 7

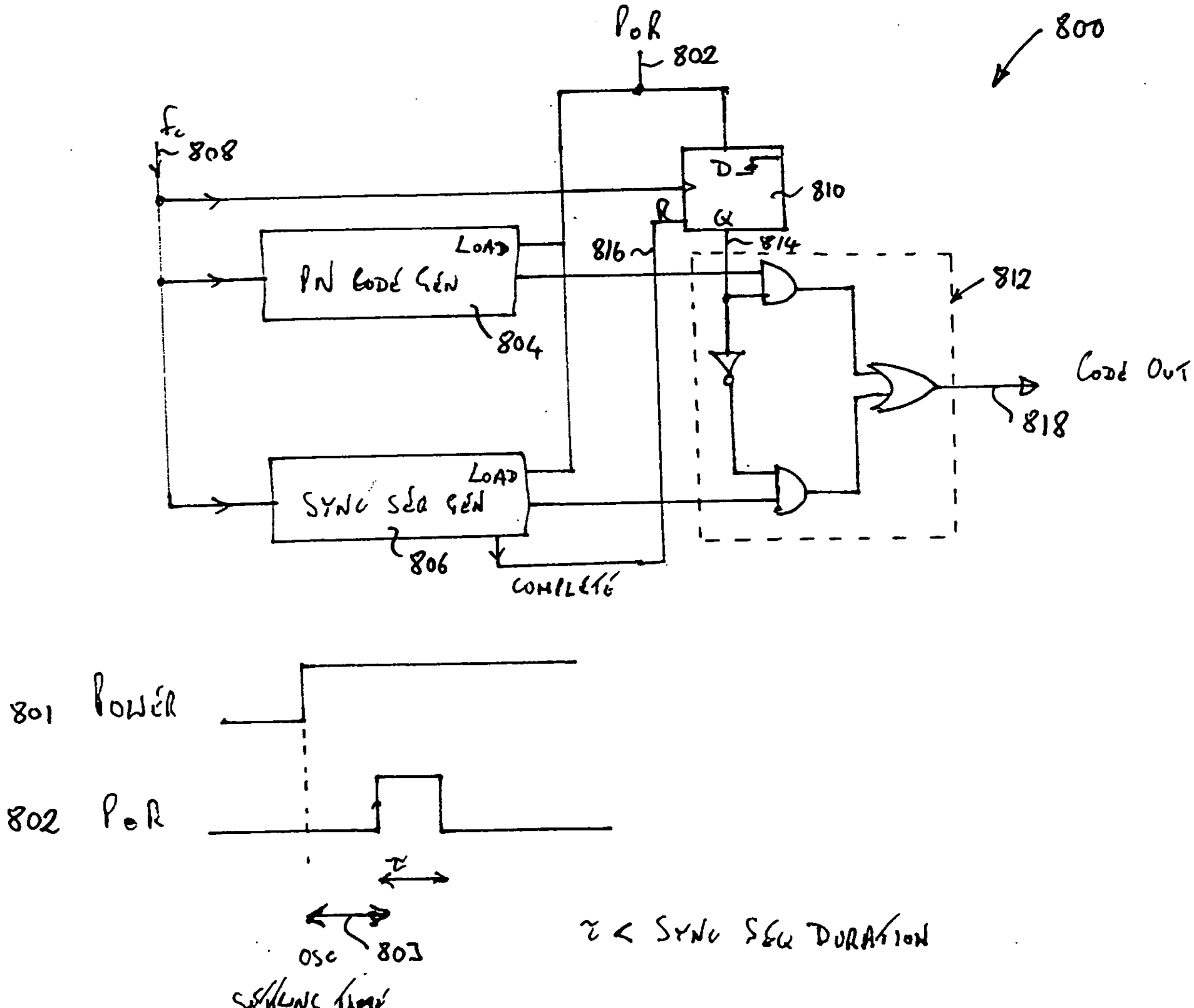


FIGURE 8

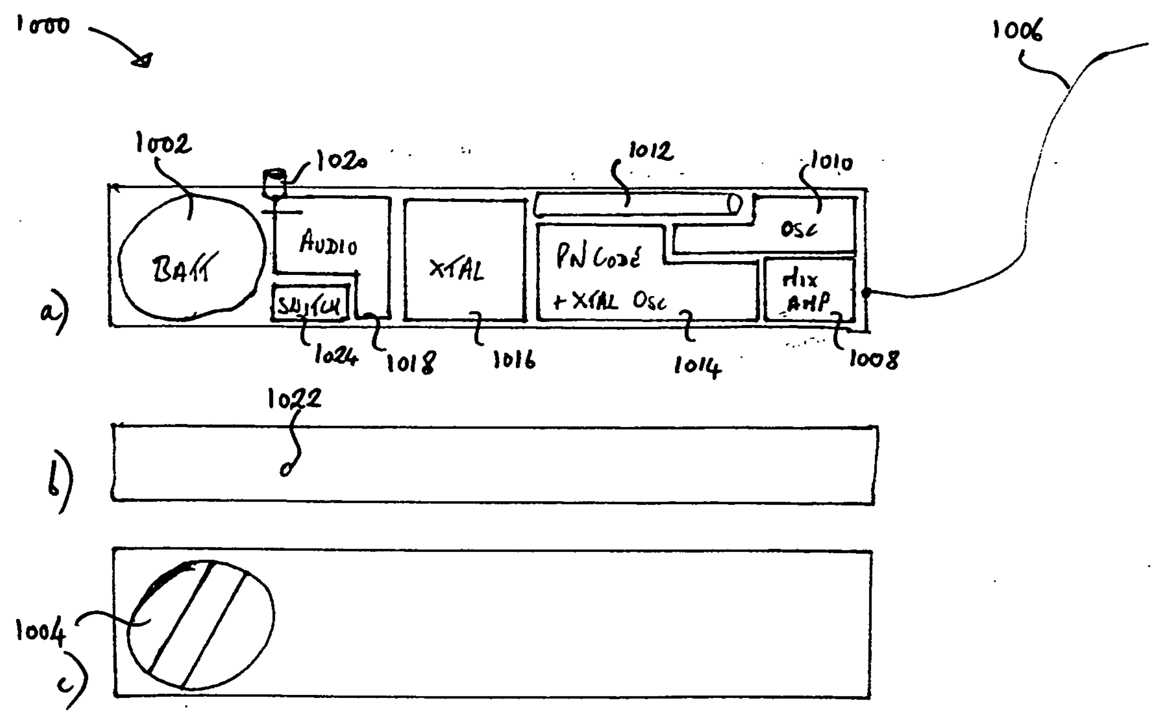


FIGURE 10

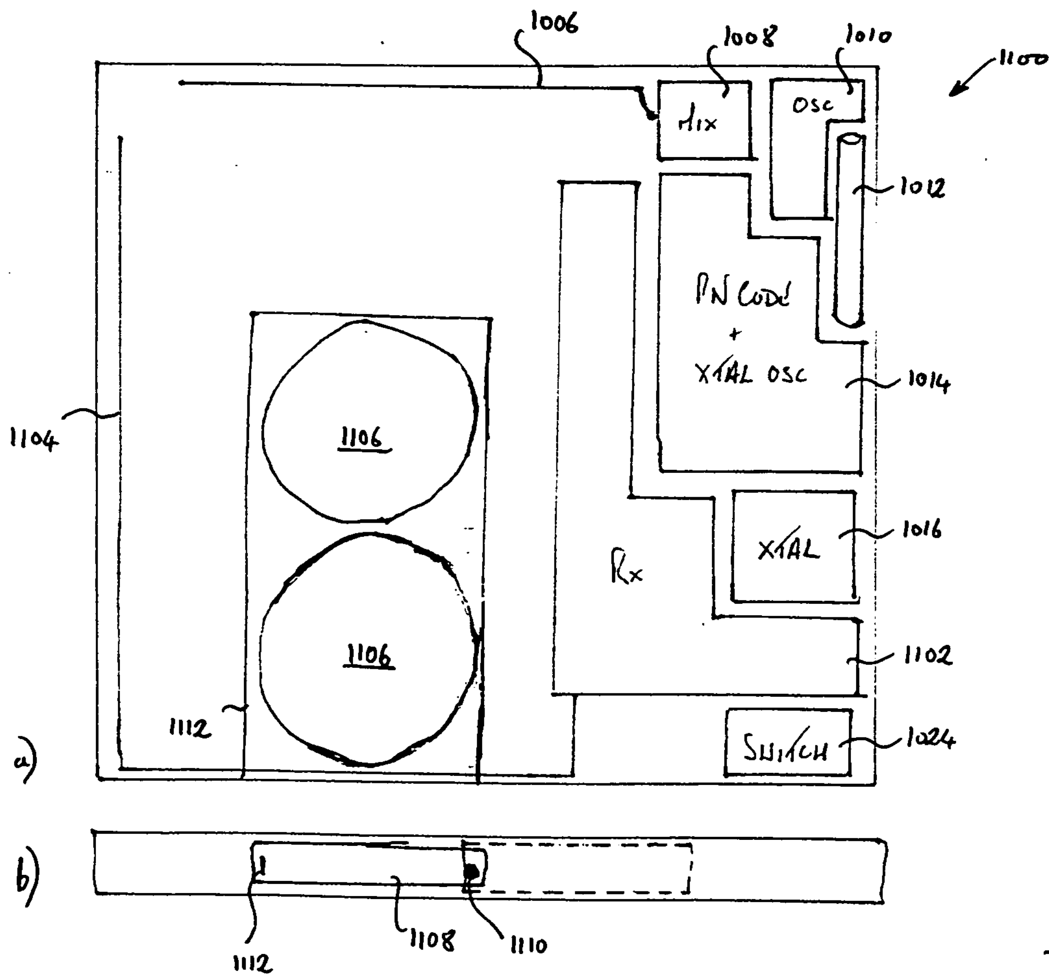


FIGURE 11

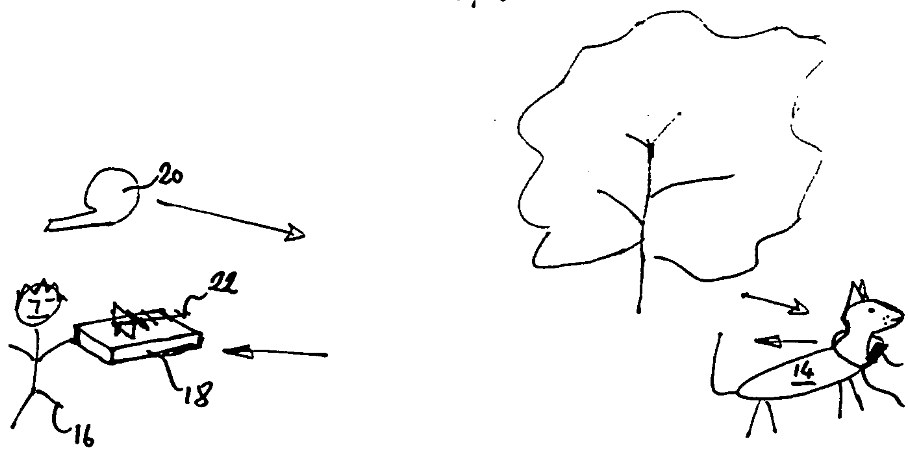


FIGURE 1

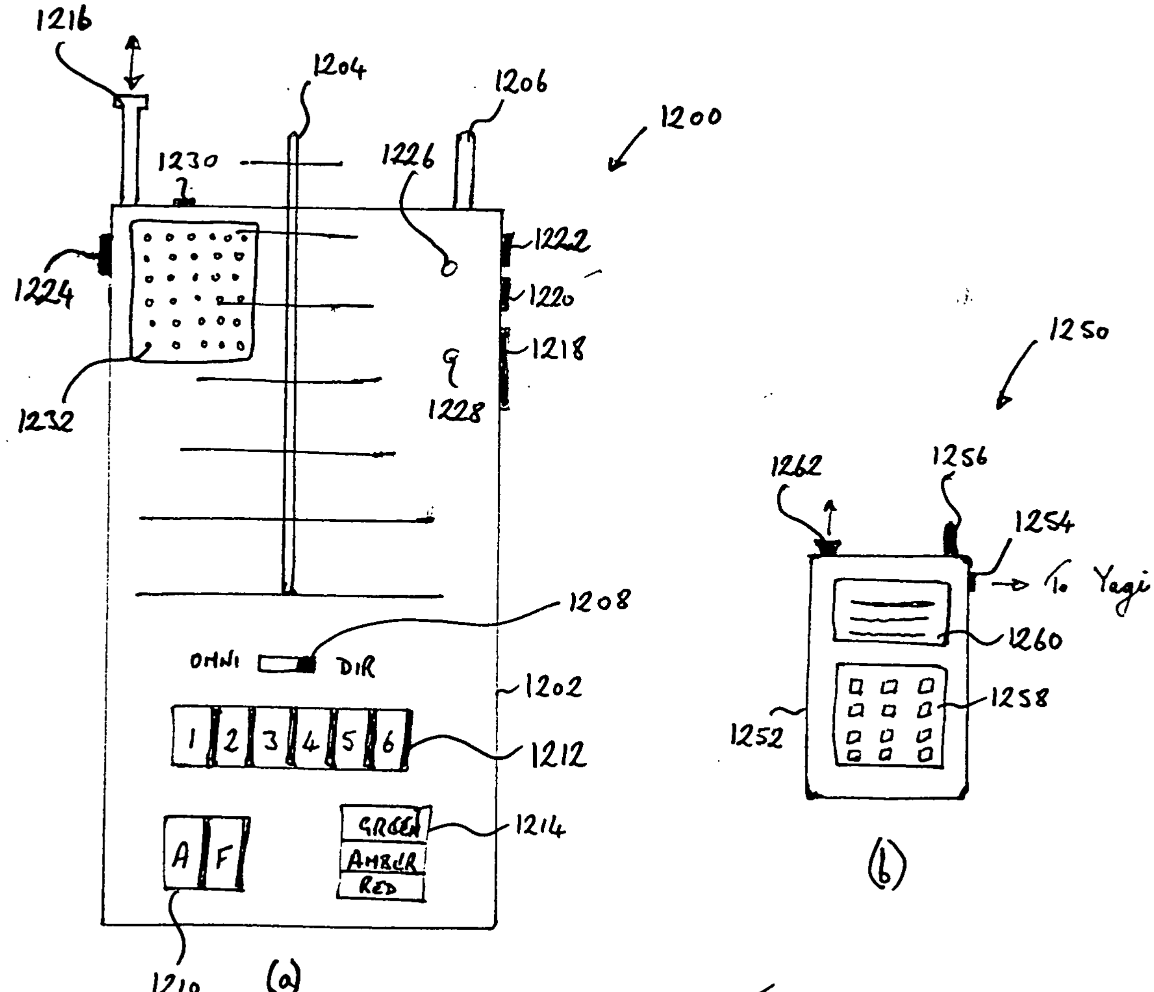


FIGURE 12

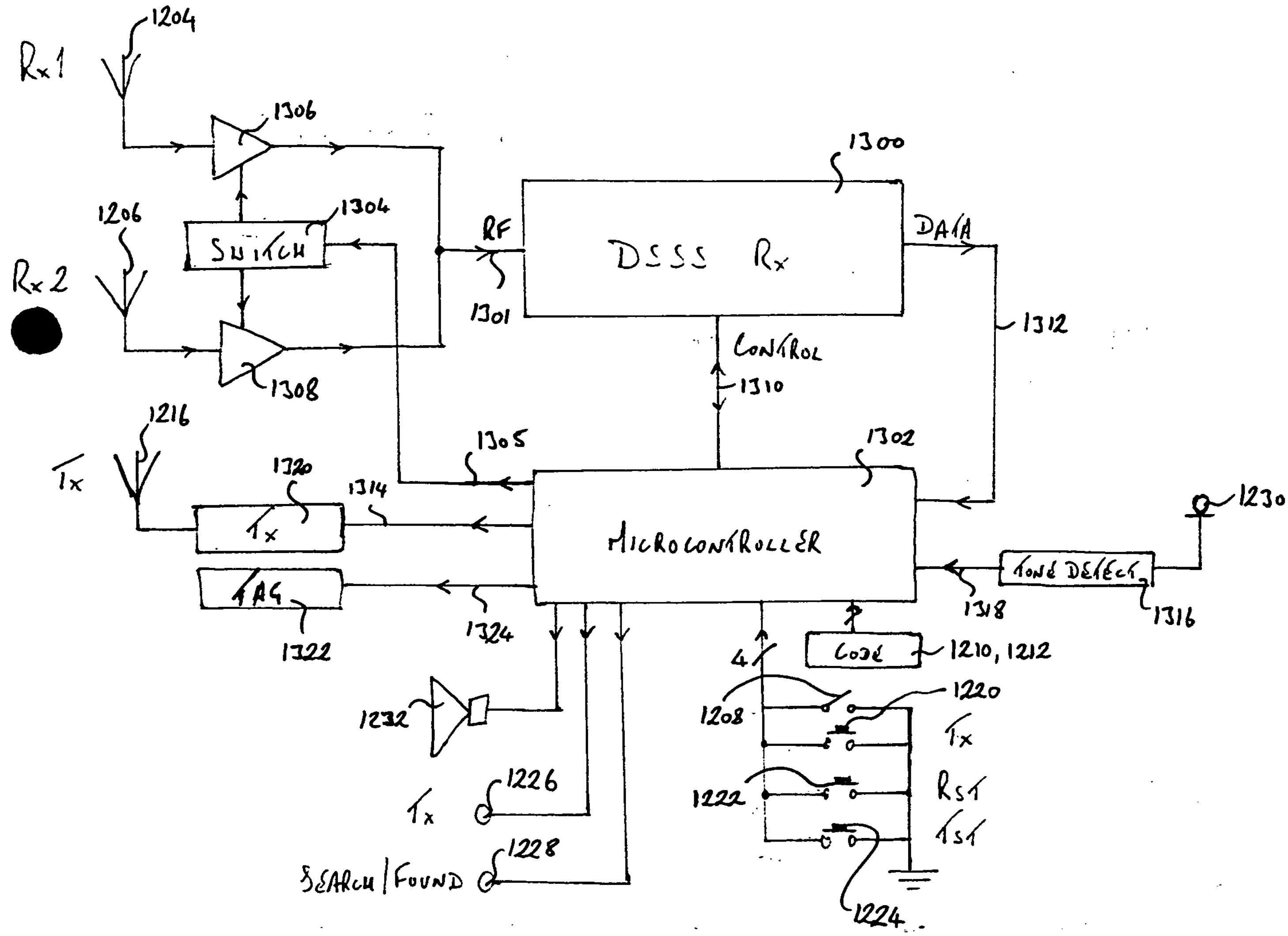

1204
Rx1
1306
1300
1206
1304
SWITCH
RF
DSSS Rx
DATA
Rx2
1301
1312
CONTROL
1310
1308
1216
1305
1302
Tx
1320
1314
1230
Tx
MICROCONTROLLER
TAG
TONE DETECT
1318
1316
1322
1324
4
CODE
1210, 1212
1208
1220
1232
Tx
1226
RST
1222
Tx
TST
1228
SEARCH/FOUND
1224

FIGURE 13

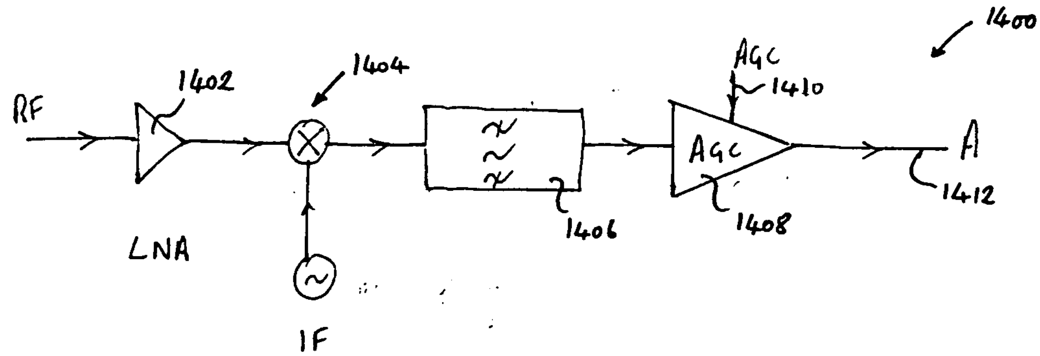


FIGURE 14

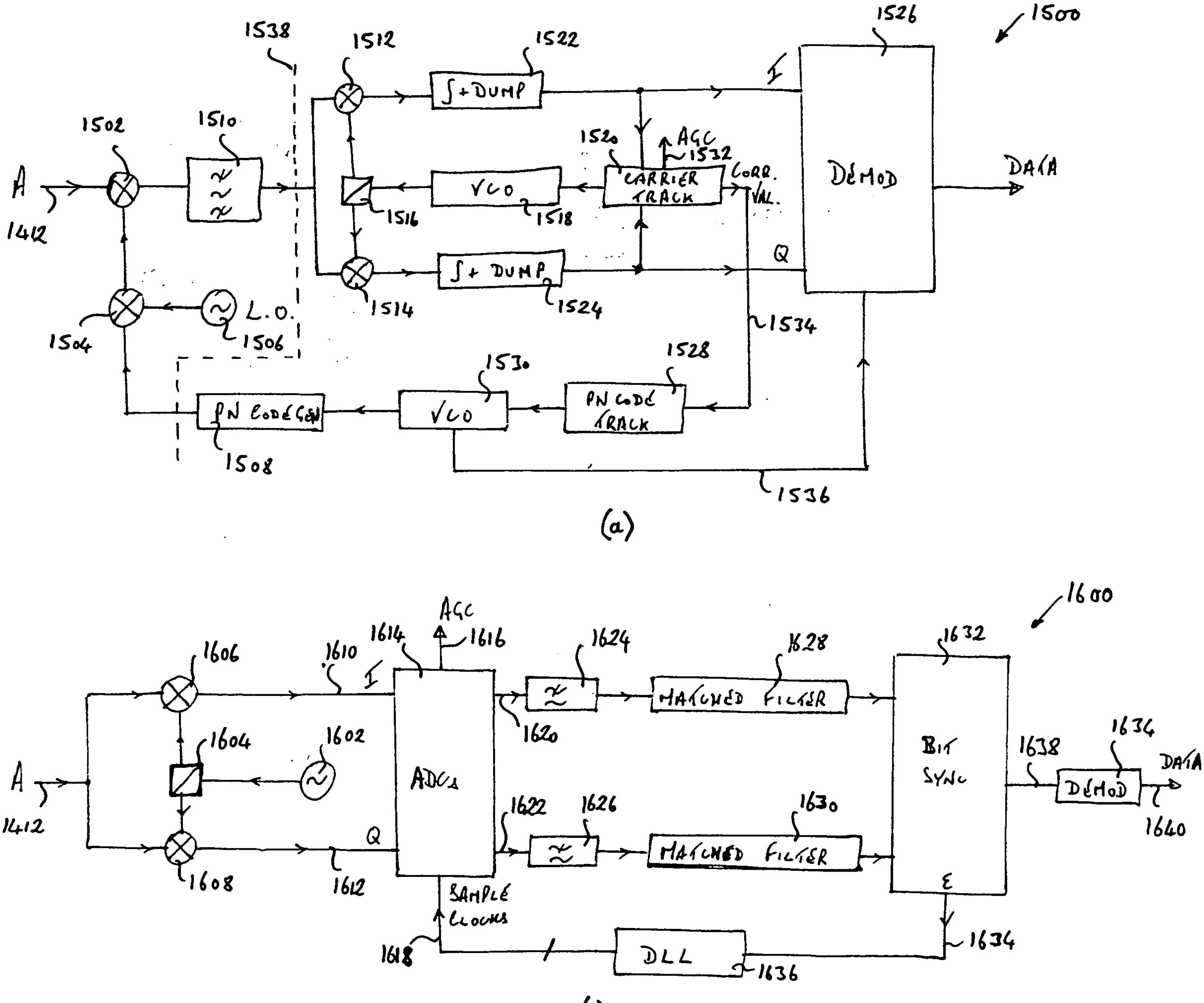


FIGURE 15

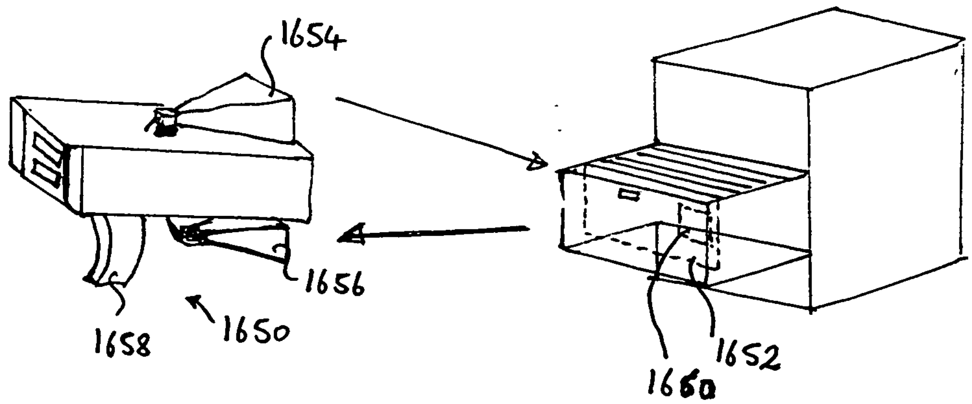


FIGURE 16

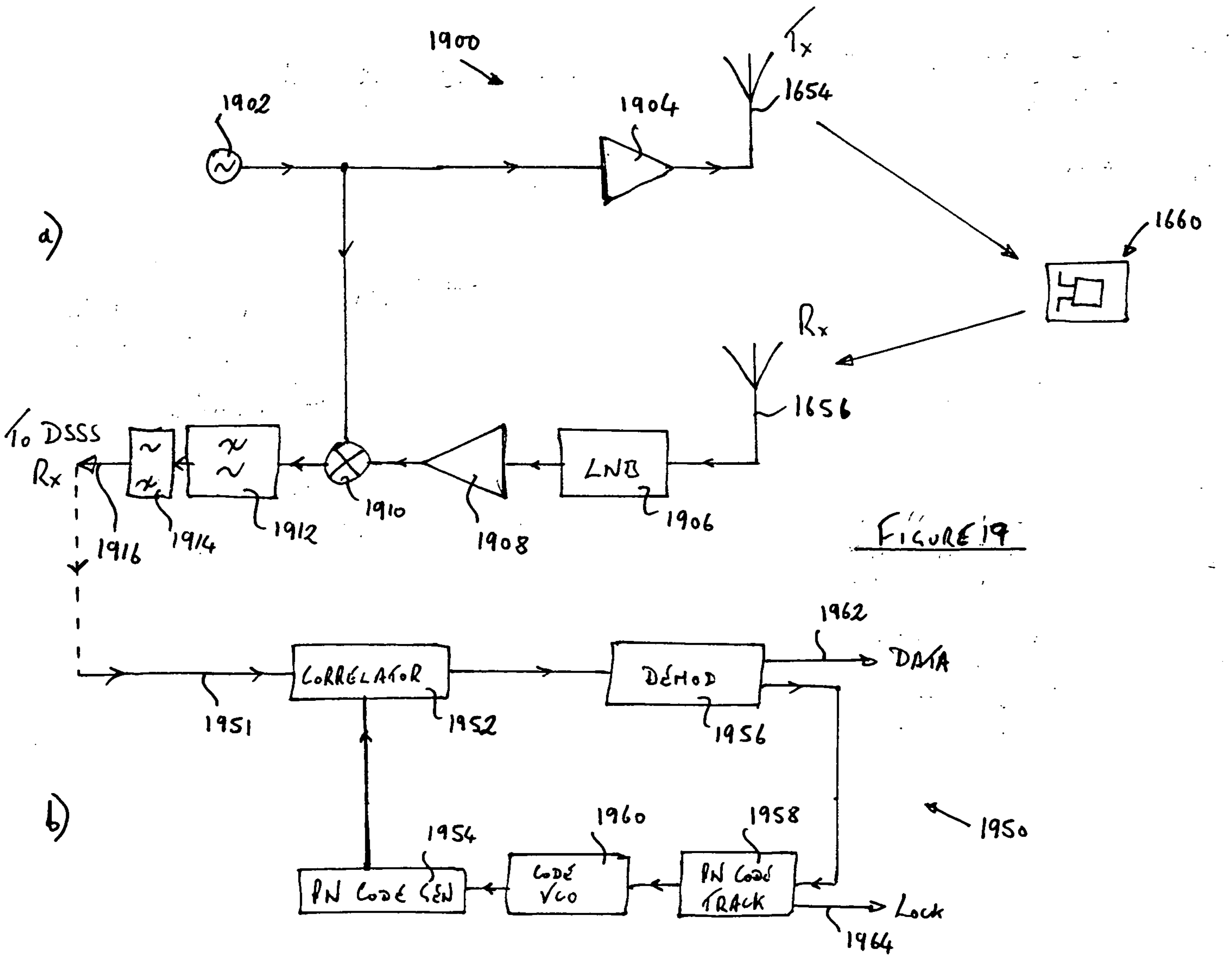


FIGURE 19

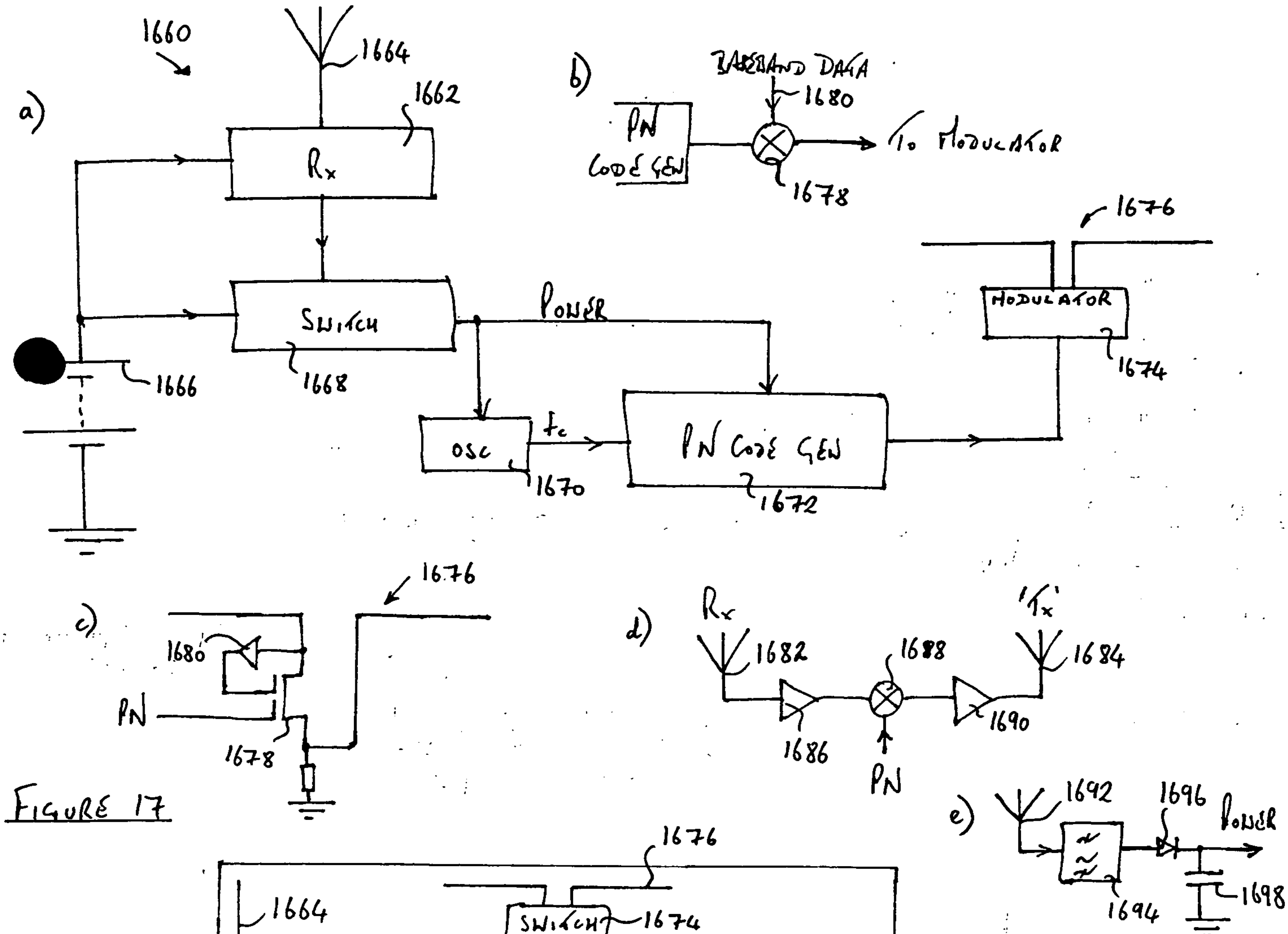


FIGURE 17

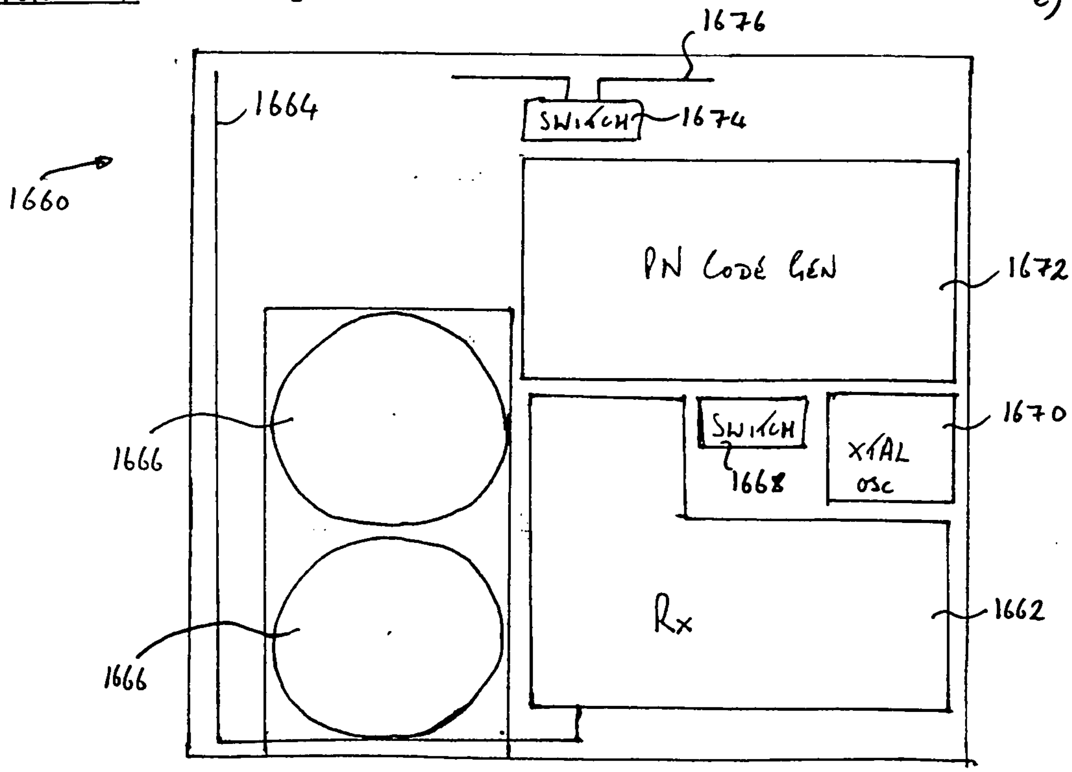


FIGURE 18